



Trinity College Dublin

Coláiste na Tríonóide, Baile Átha Cliath

The University of Dublin

Space Weather: Origins and Impacts

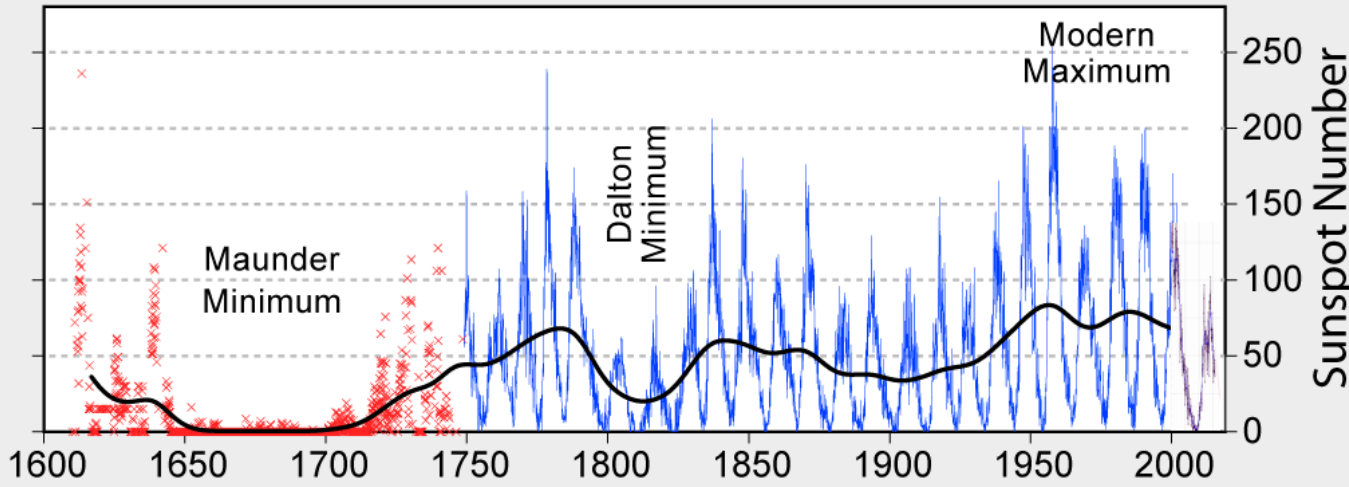
Sophie A. Murray

2017-02-16

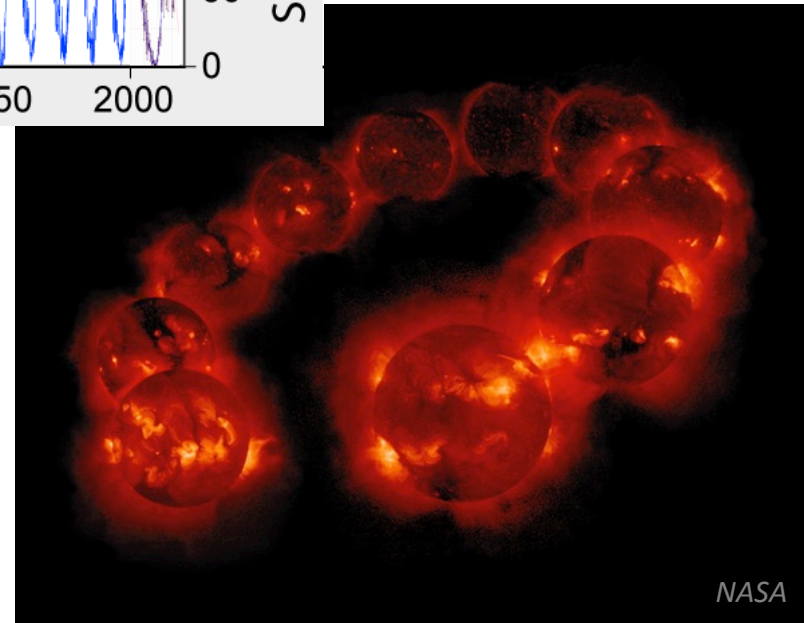
Space Climate

Long term changes
- tens to thousands of years

400 Years of Sunspot Observations



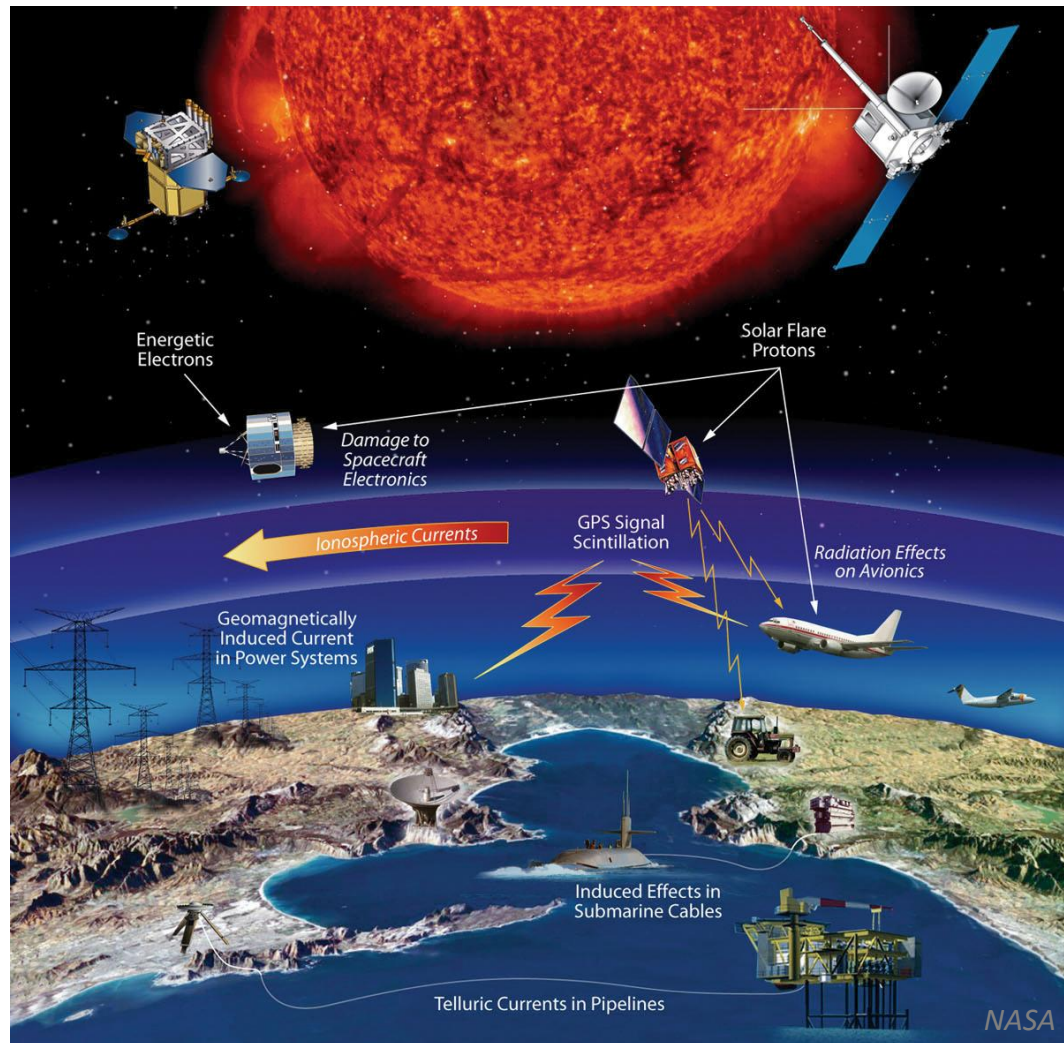
Global Warming Art Project



NASA

Space Weather

Short term changes
- hours to days





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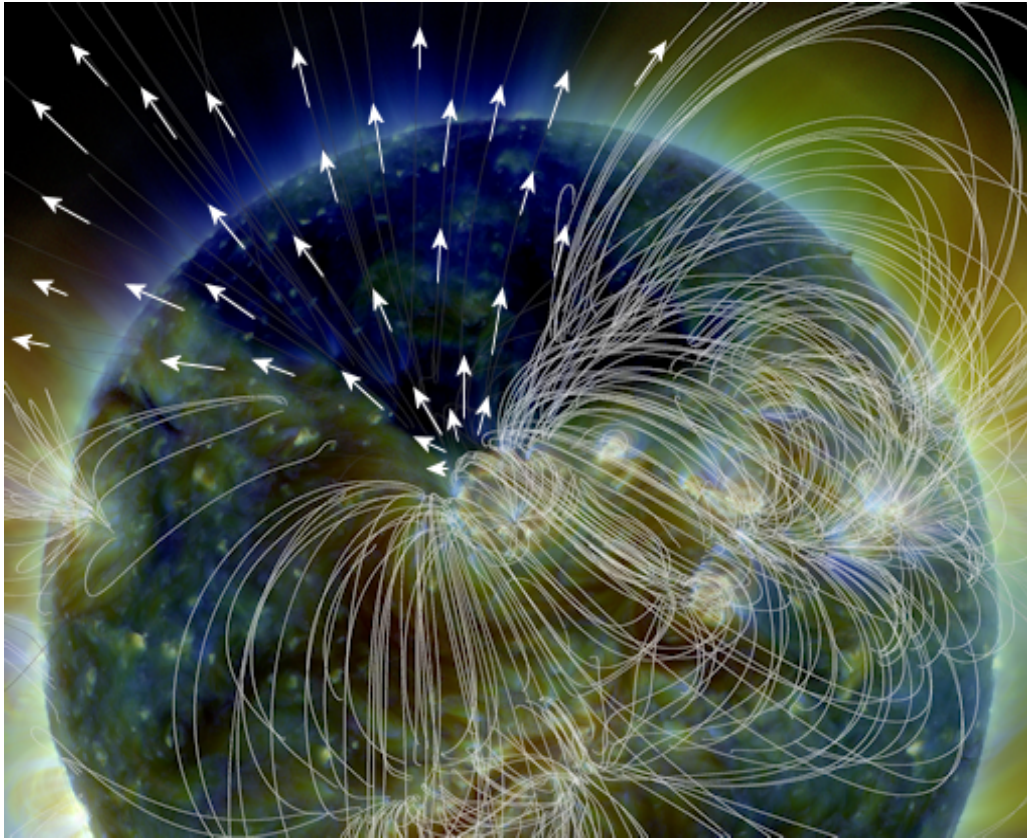
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Origins

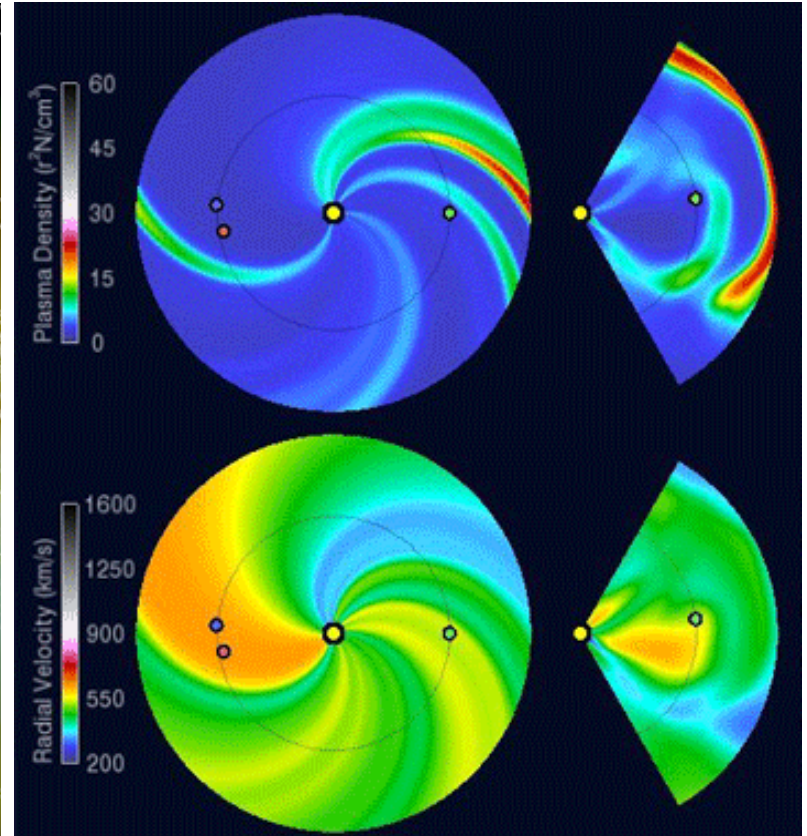


Solar Wind

Fast ($\sim 400 - 800$ km/s, ~ 1.5 million km/h), tenuous (~ 5 cm $^{-3}$; 1 atm: $\sim 10^{19}$ cm $^{-3}$) plasma flow (electrons & ions: $\sim 96\%$ H $^{+}$, 4% He $^{2+}$), with embedded magnetic field.



spaceweather.com



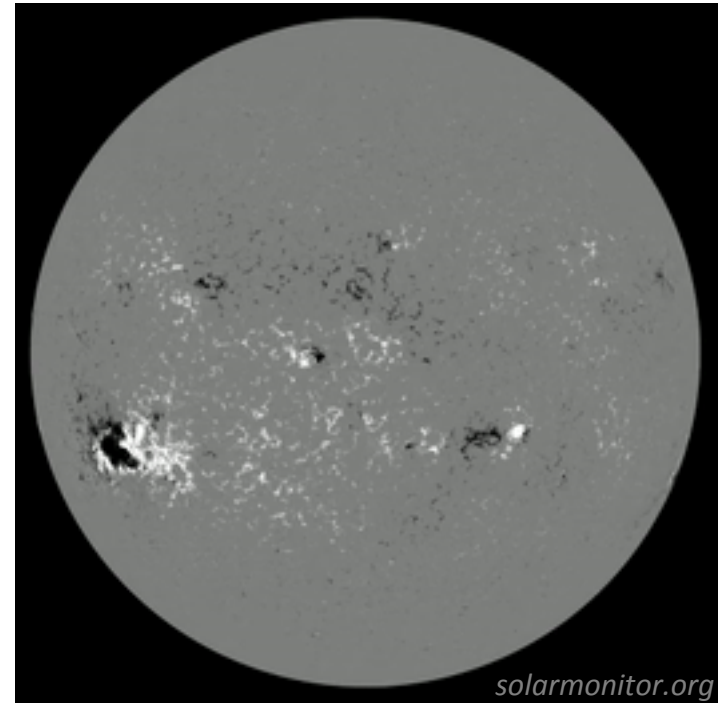
Met Office

Sunspots

Regions of strong magnetic field
(1,000s Gauss; 1 Tesla = 10^4 Gauss)



Sunspot groups



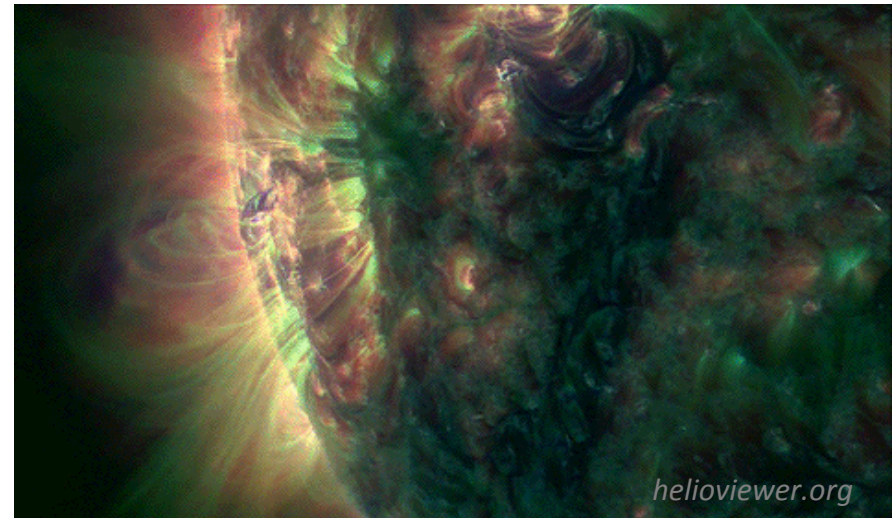
Active regions

Solar Flares

Energy stored in sunspot magnetic fields released in form of radiation across entire electromagnetic spectrum ($\sim 10^{32}$ erg; 10^{25} J)



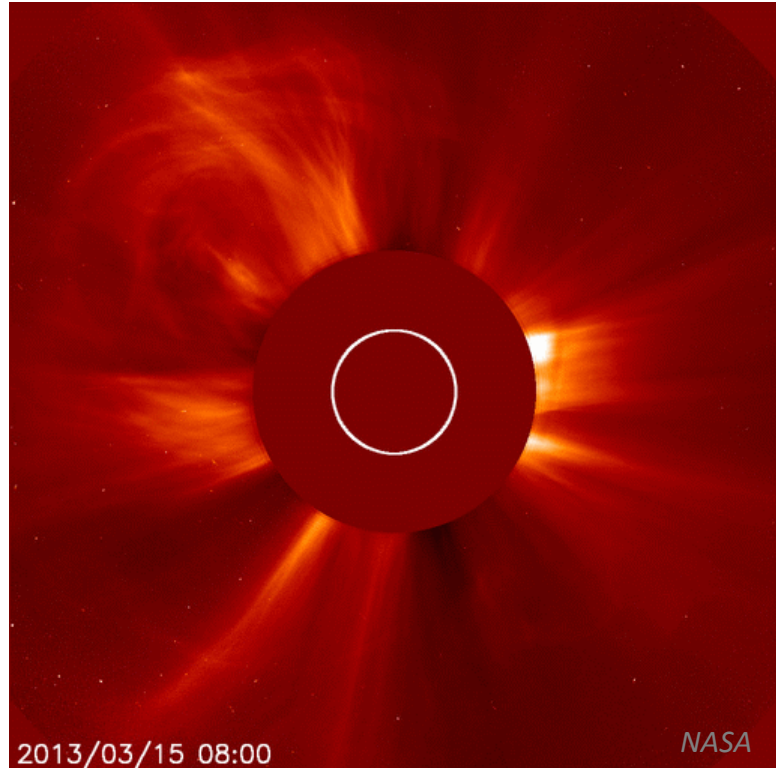
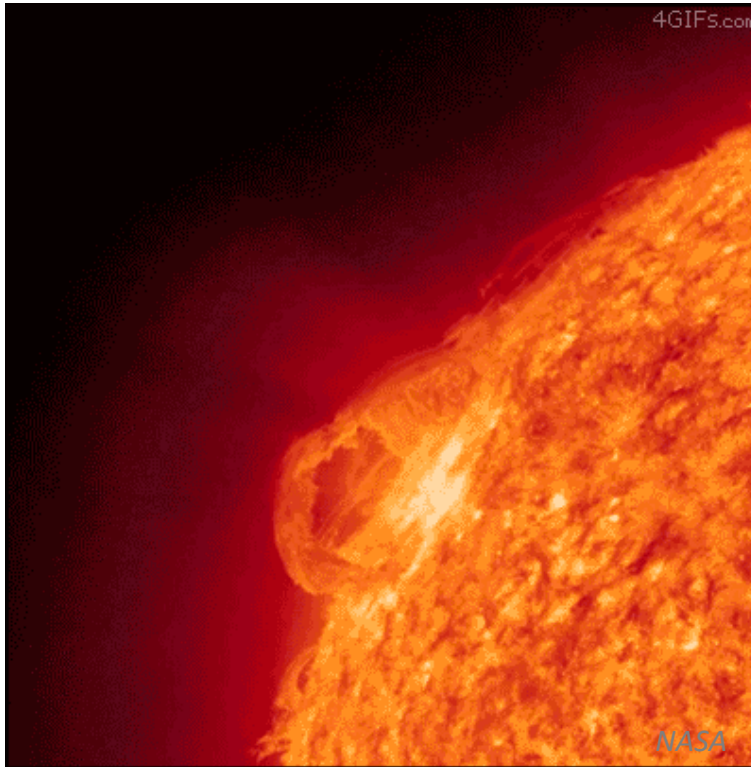
Confined



Eruptive

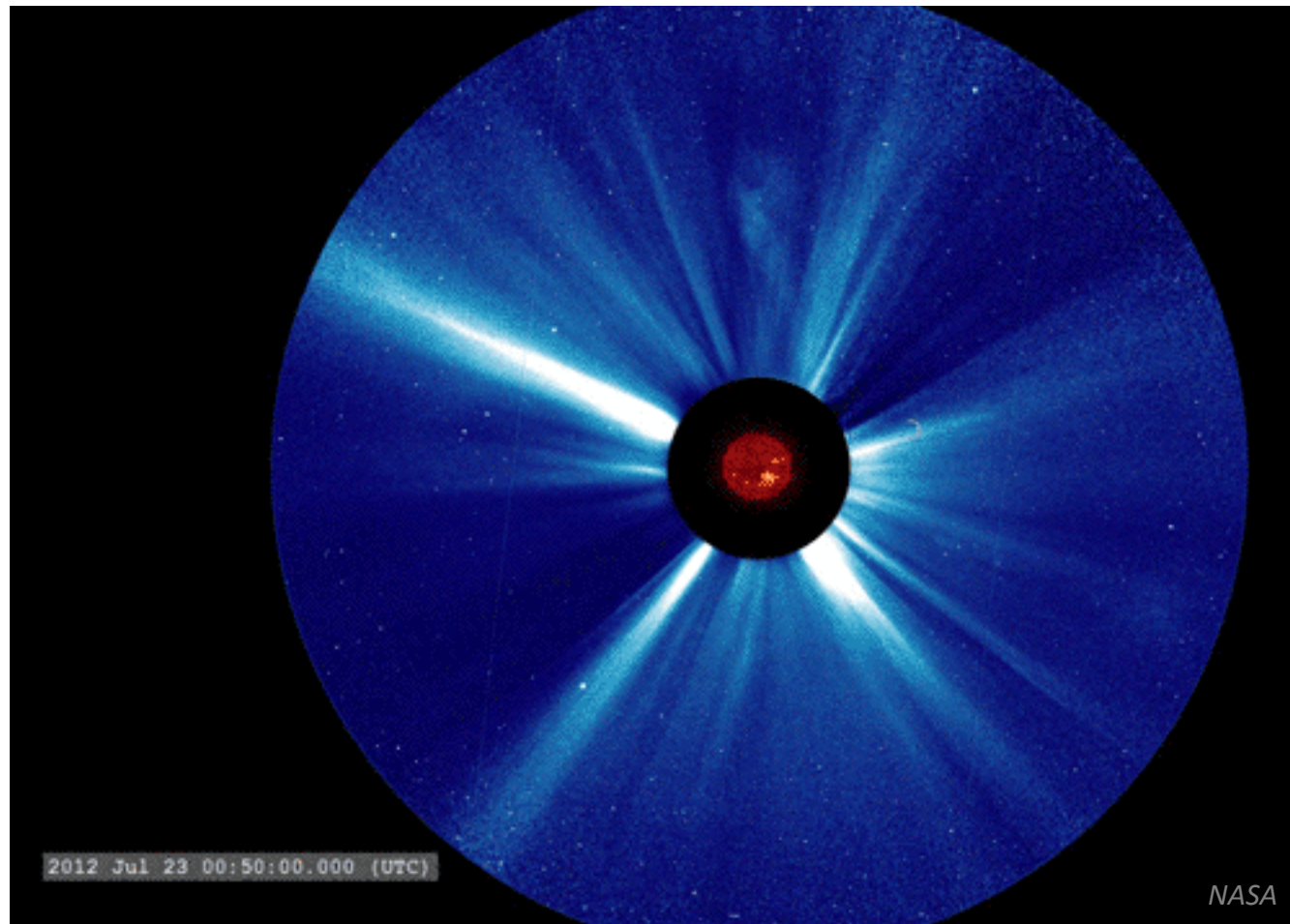
Coronal Mass Ejections

Fast (100s - 1000s km/s),
expulsions of plasma (up
to 10^{13} kg)



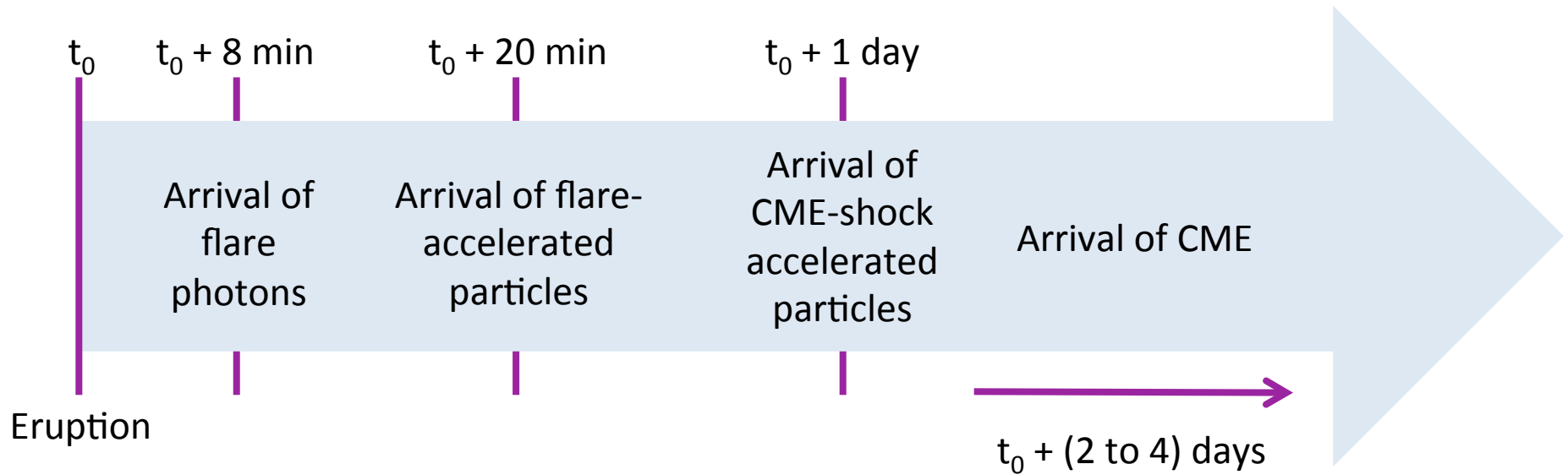
Solar Energetic Particles

High-energy protons and electrons, ranging from a few tens of keV to GeV.



Eruption Timeline

Arrival at Earth





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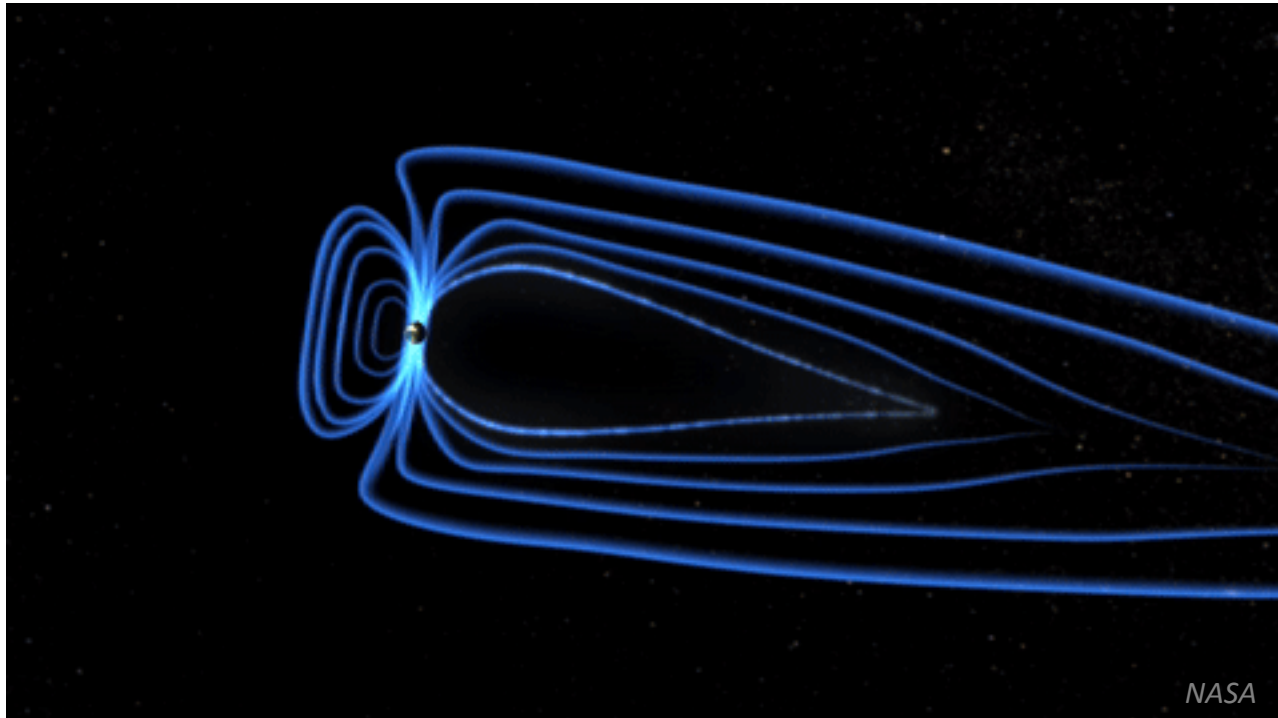
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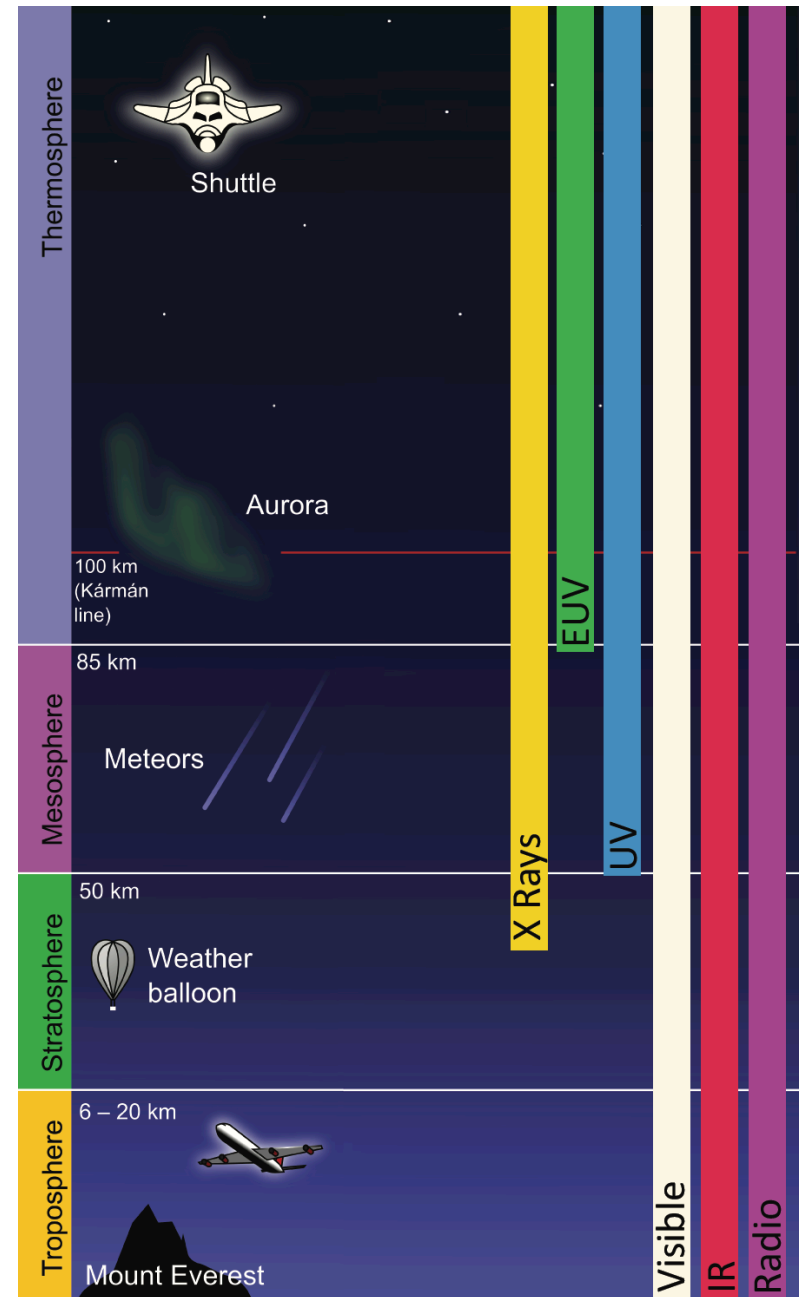
Impacts



Magnetosphere

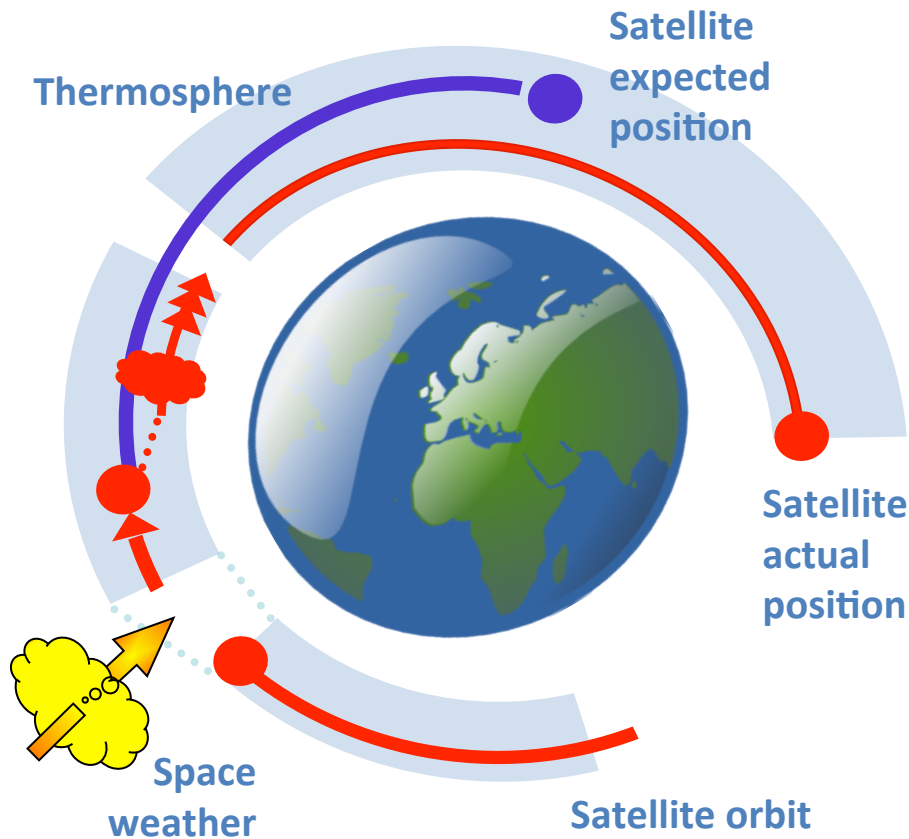


Atmosphere

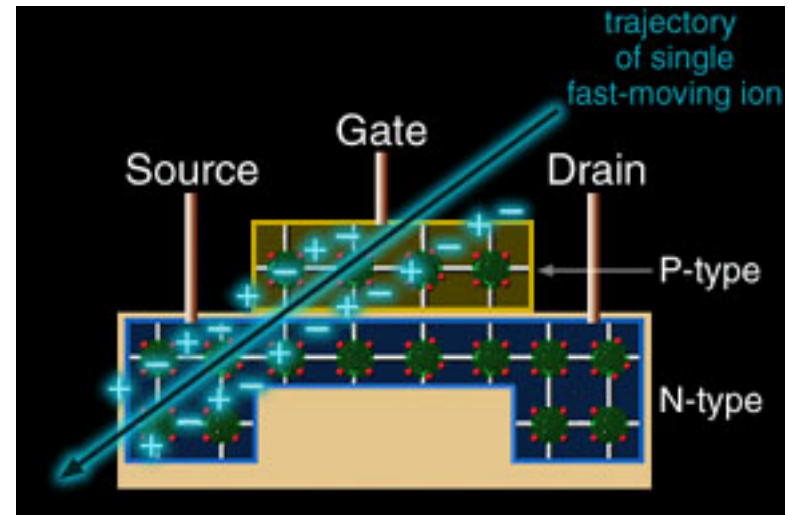


NOAA

Satellite Operations



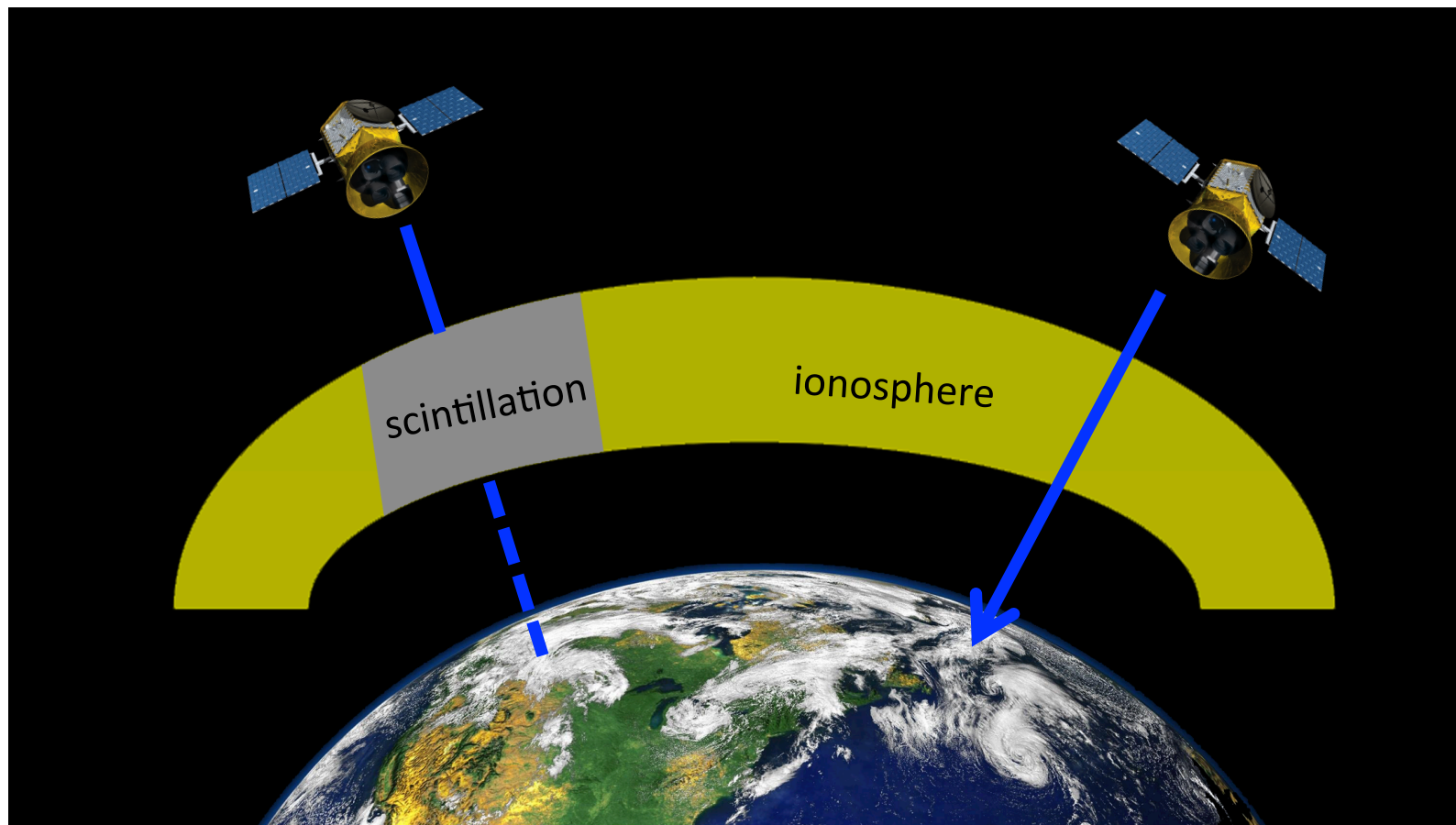
Highly energetic ions penetrate electronic components, which can result in improper commands within the spacecraft or incorrect data from an instrument. Less energetic particles contribute to a variety of spacecraft surface charging problems.



Windows on the Universe

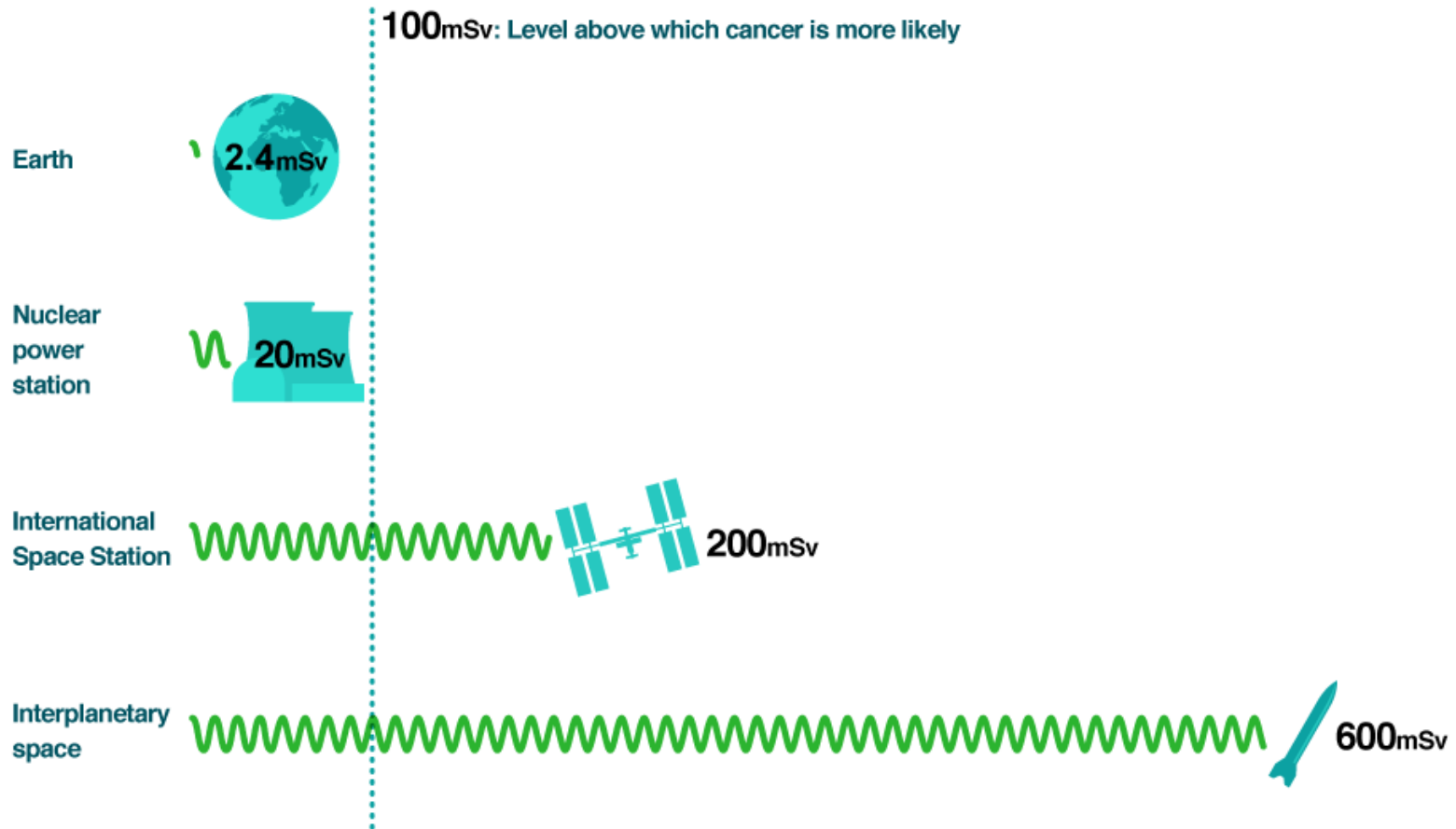
Navigation Systems

Disturbances in the ionosphere can cause degradation in GPS range measurements and in severe circumstances, loss of lock by the receiver on the GPS signal.



Human Spaceflight

Energetic particles present a health hazard to astronauts on space missions as well as polar airline crews. Astronauts outside spacecraft are less protected and more exposed to space radiation.

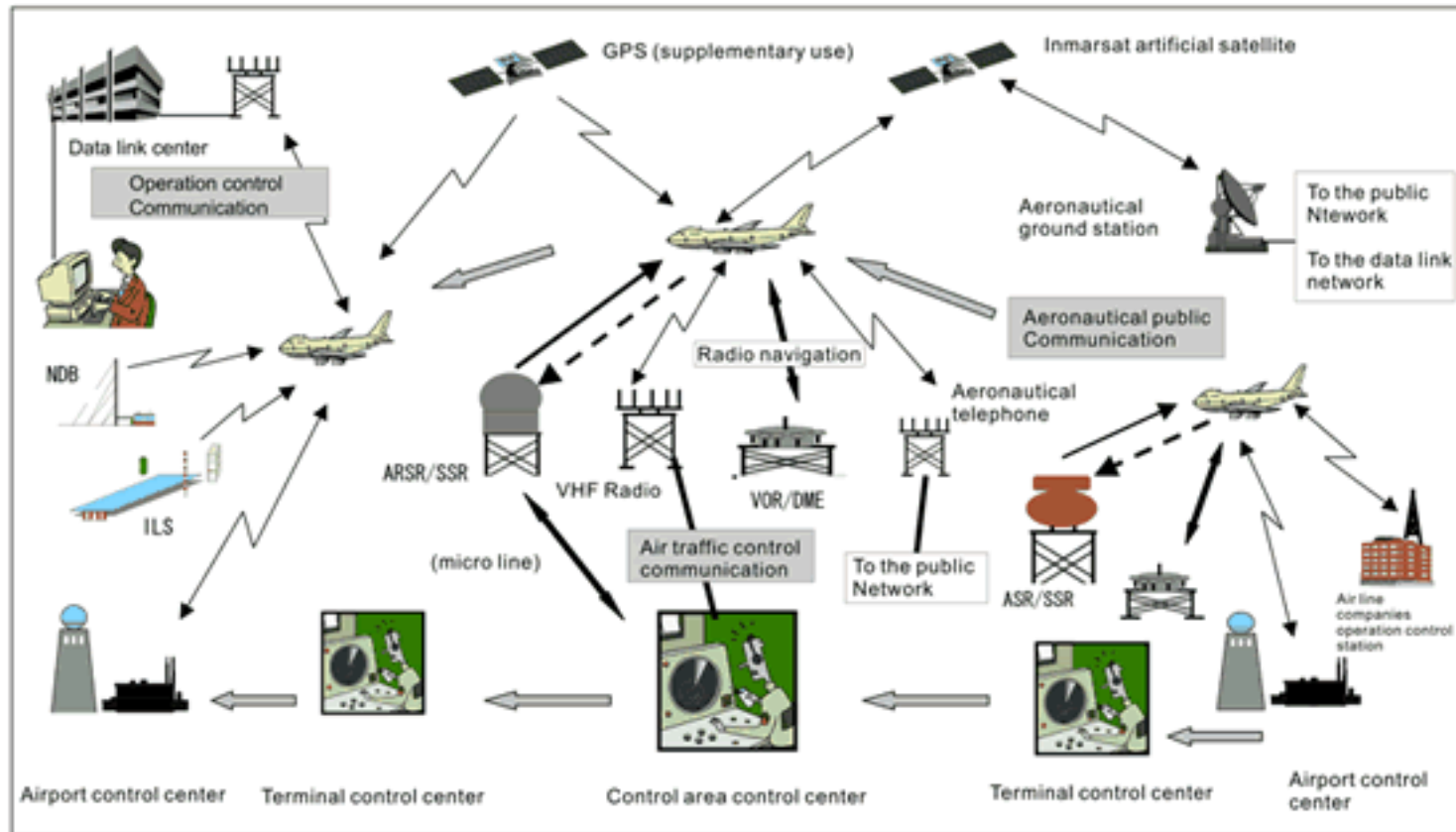


mSv = millisievert (a measure of the biological effects of radiation)

BBC

Aviation

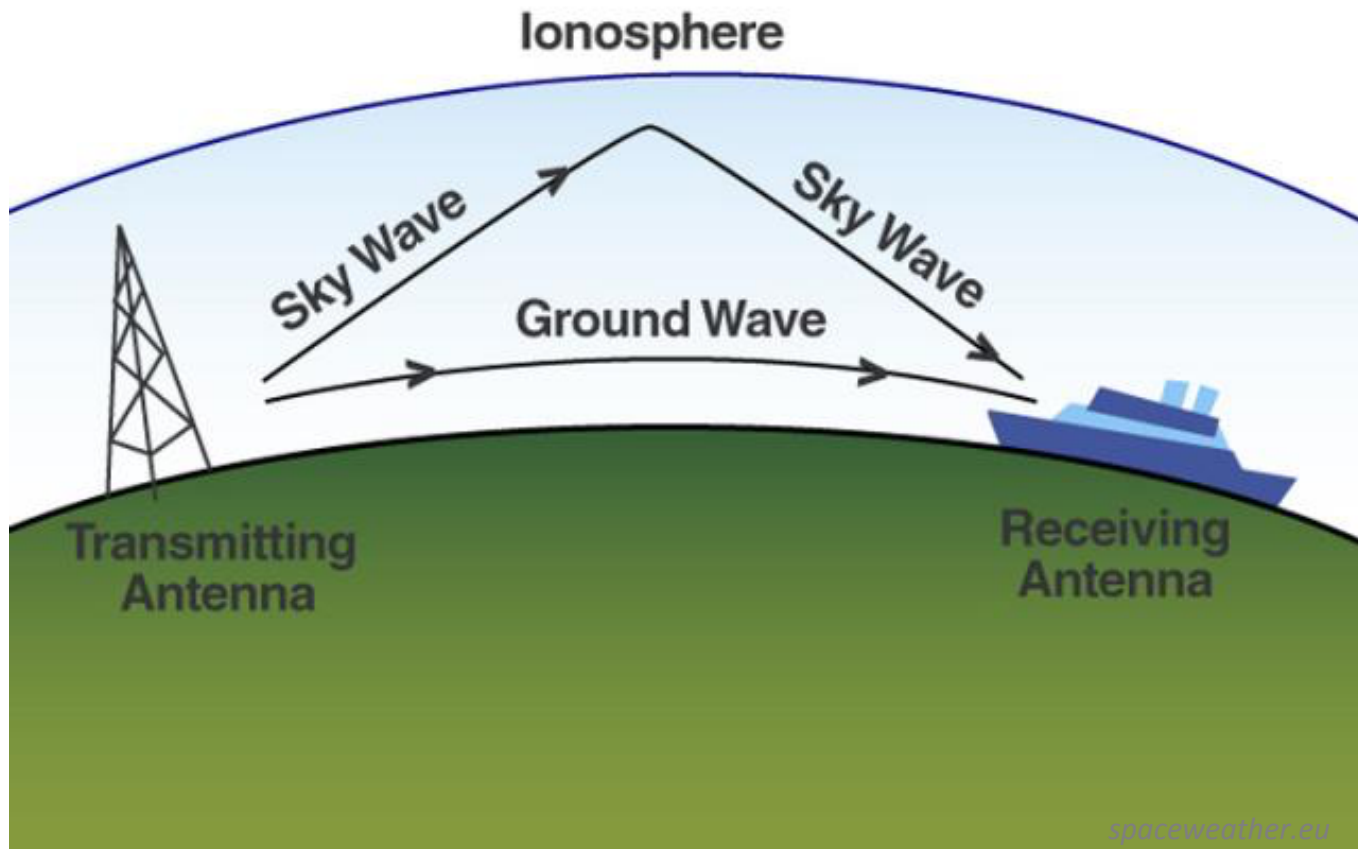
Space weather storms can cause lost or degraded communications, radiation hazards to crew and passengers, unreliable navigational information, and problems with flight-critical electronic systems.



Japan MIC

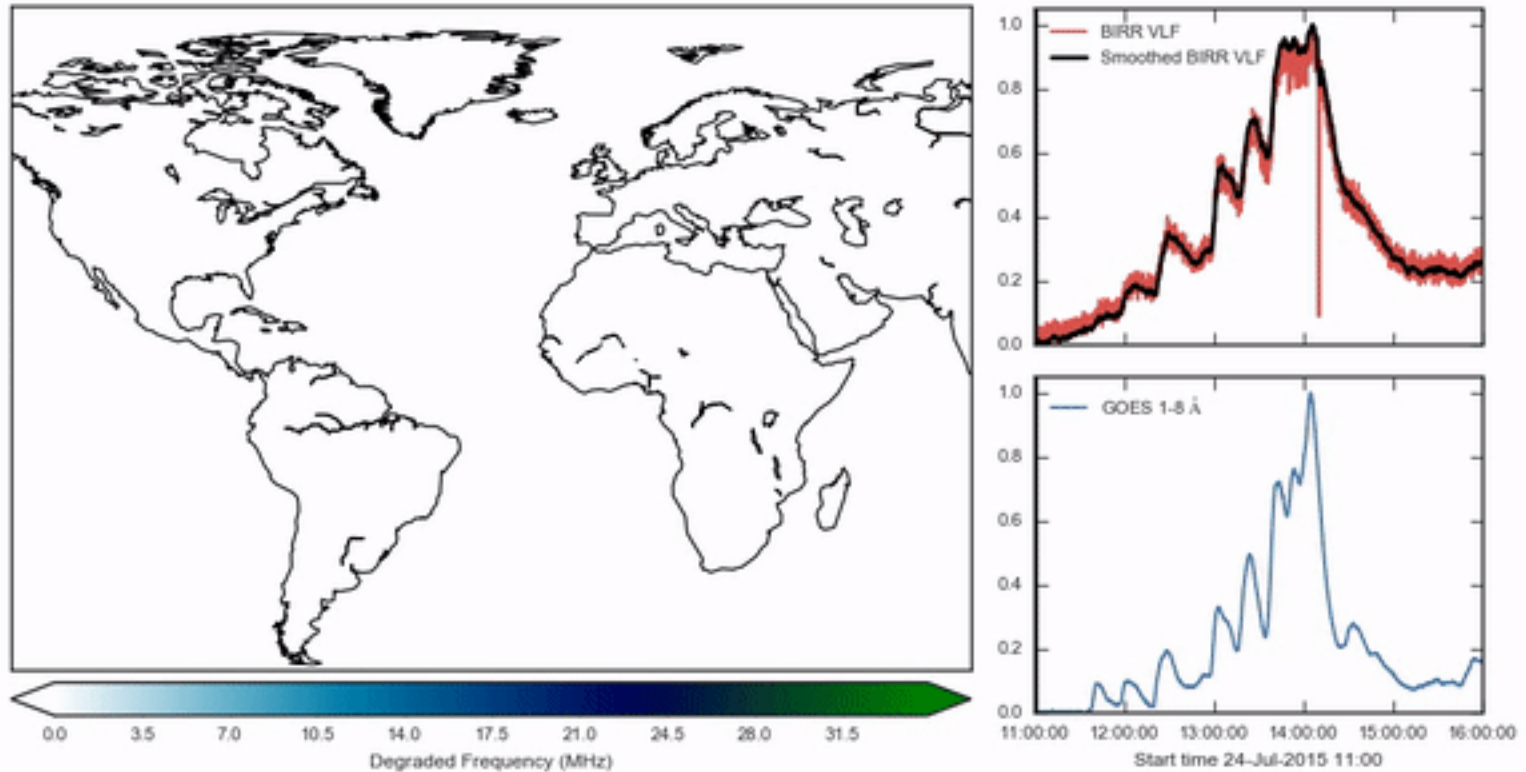
Communication

Communications at all frequencies may be affected. HF radio communications are more routinely affected because this frequency band depends on reflection by the ionosphere to carry signals great distances.





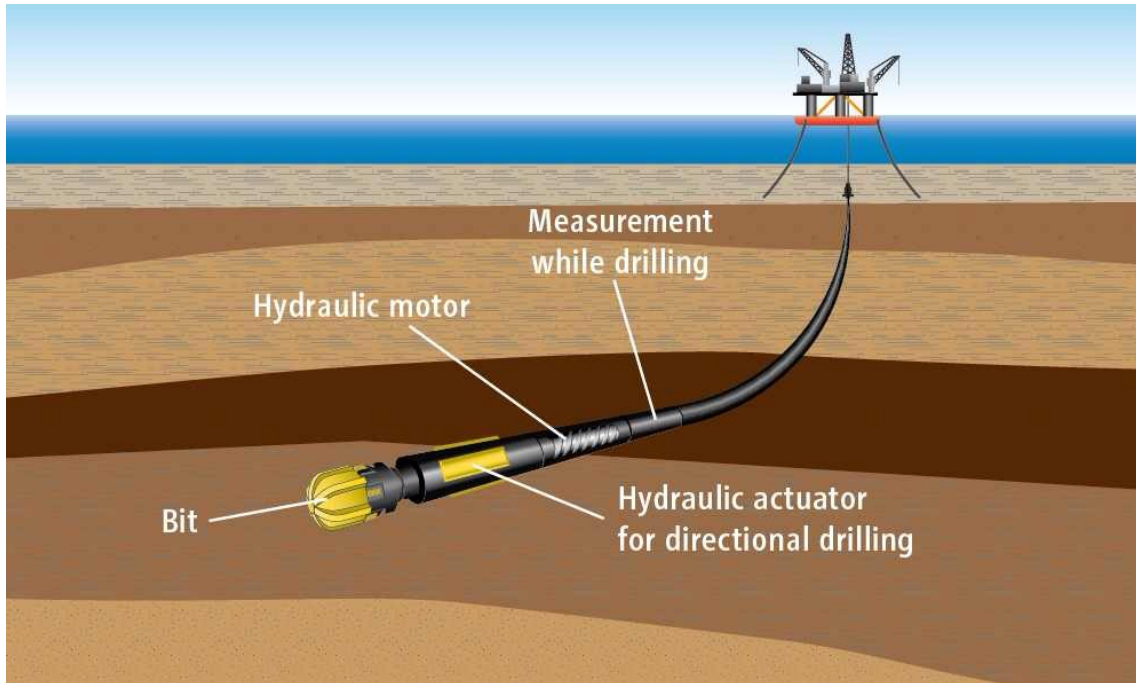
Communication



Hayes et al, in prep

Magnetic Surveying

Magnetic field changes associated with geomagnetic storms directly affect operations that use the Earth's magnetic field for guidance, such as magnetic surveys, directional drilling, or the use of magnetic compasses.

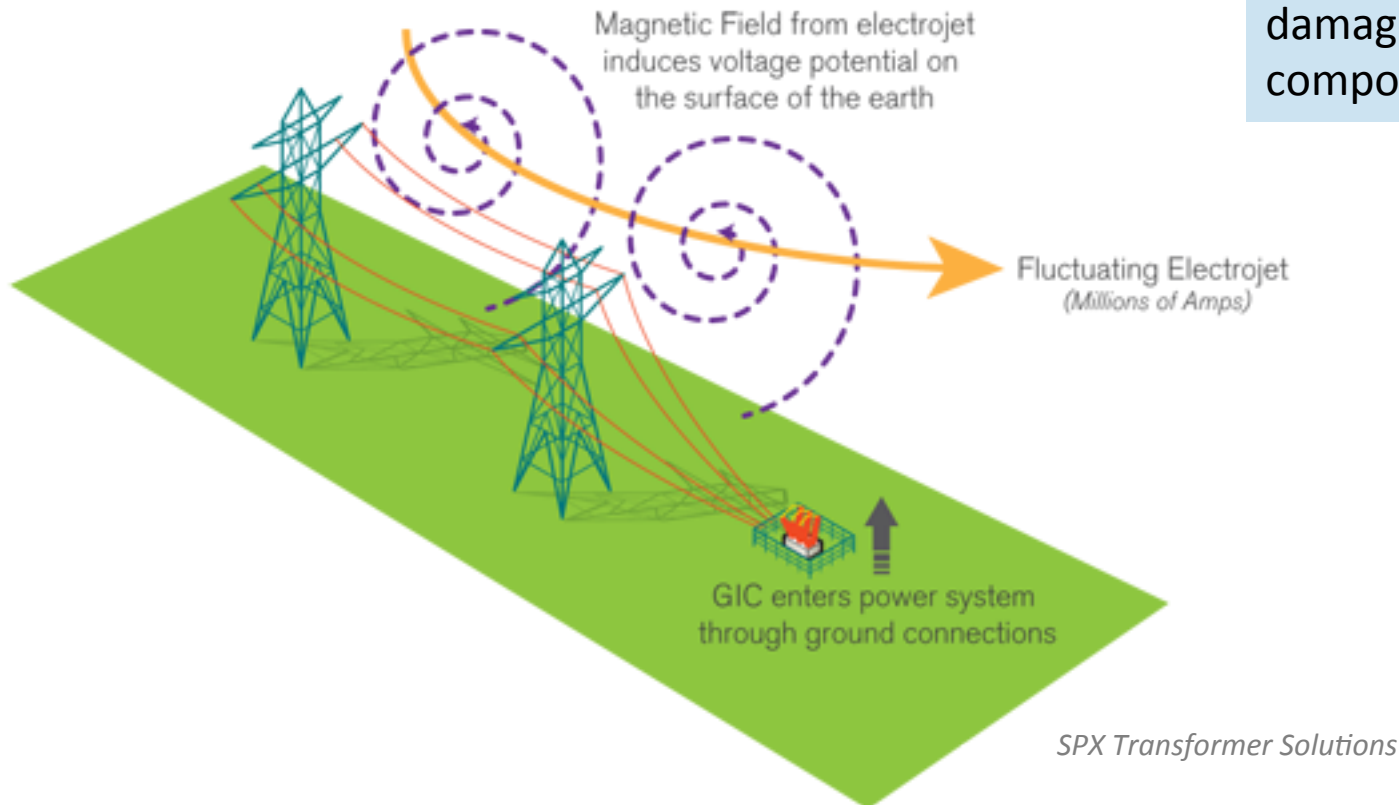


Jindal Drilling & Industries Ltd

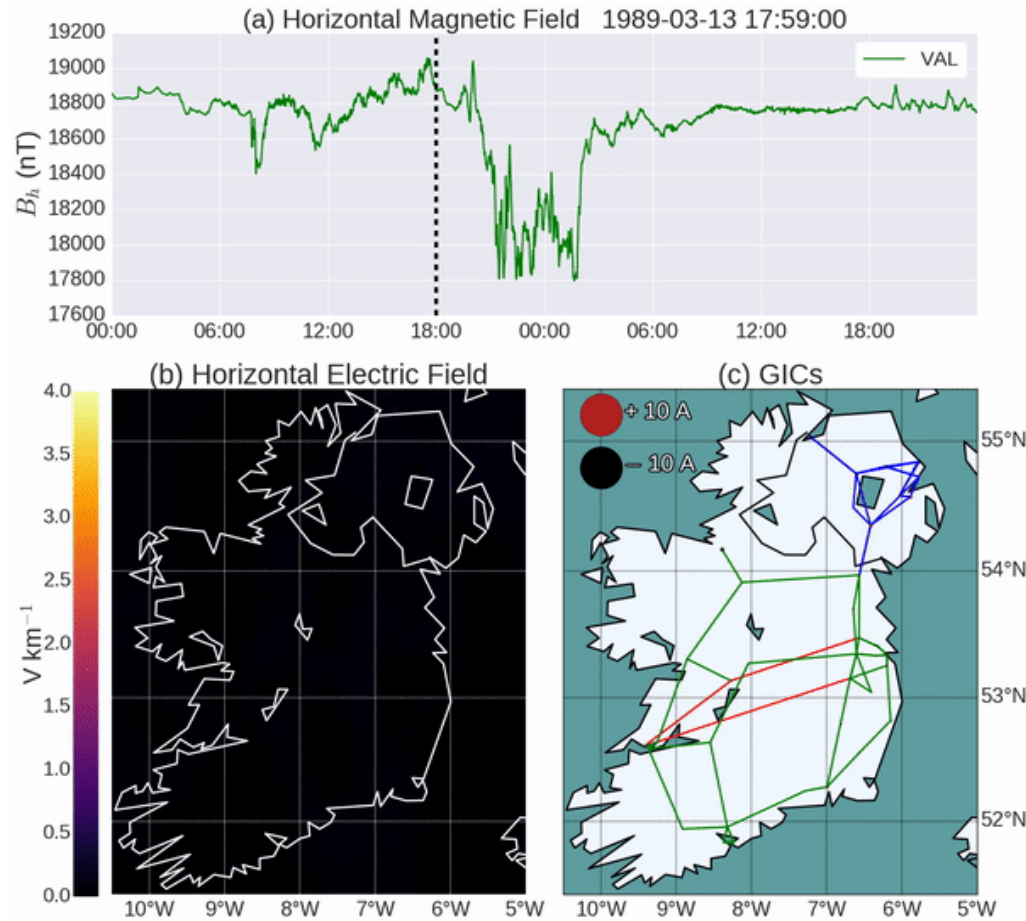


Electric Power

Large currents in the ionosphere can induce currents in power lines. Surges from these currents can cause massive network failures and permanent damage to electric grid components.

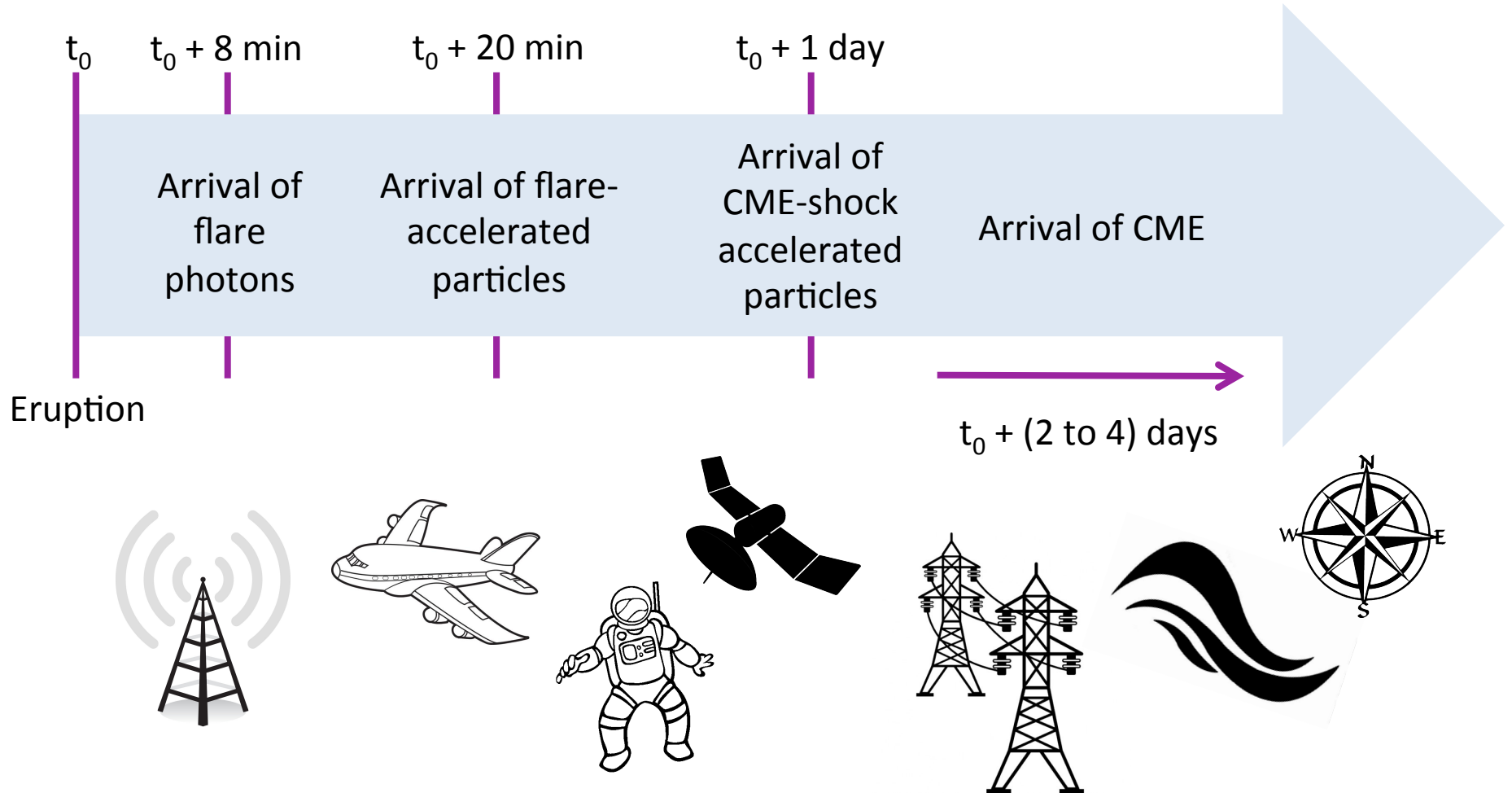


Electric Power

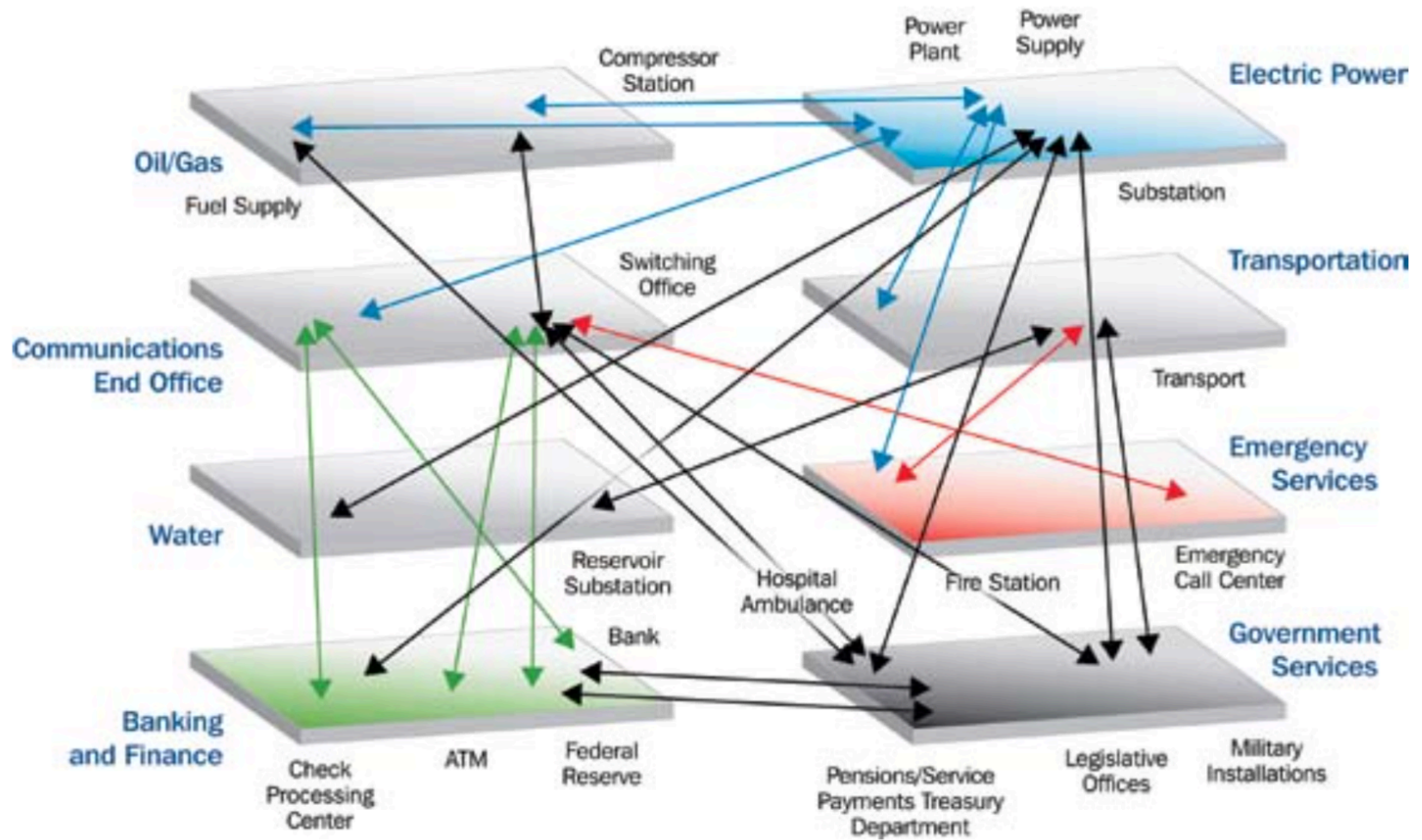


Blake et al, 2016

Eruption Timeline



The Bigger Picture



US Department of Homeland Security



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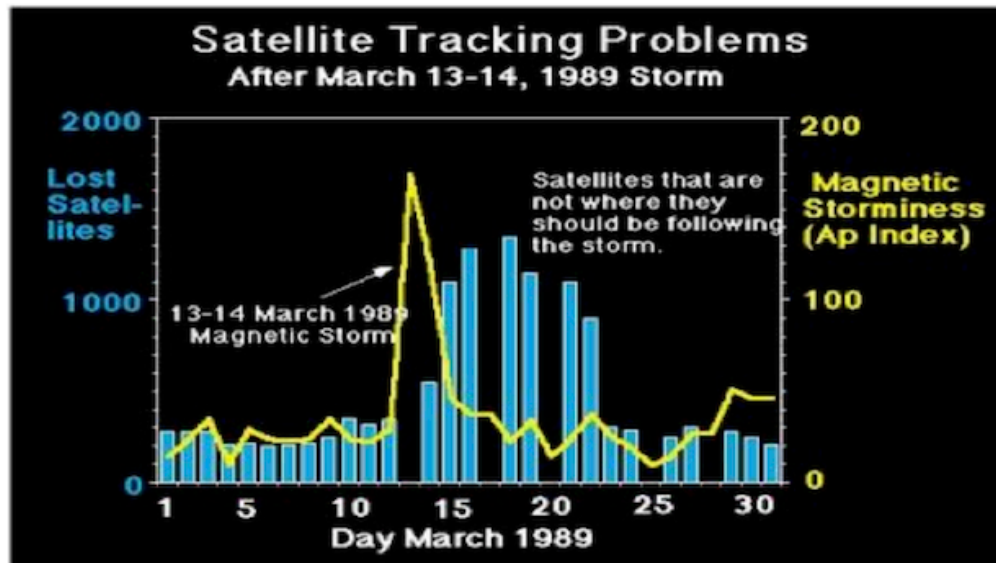
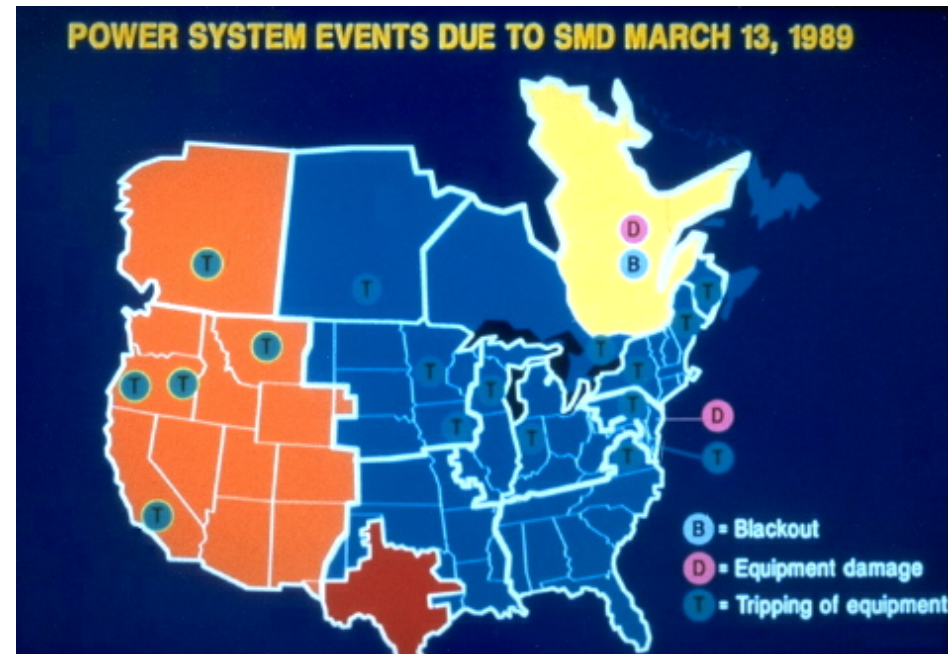
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Events

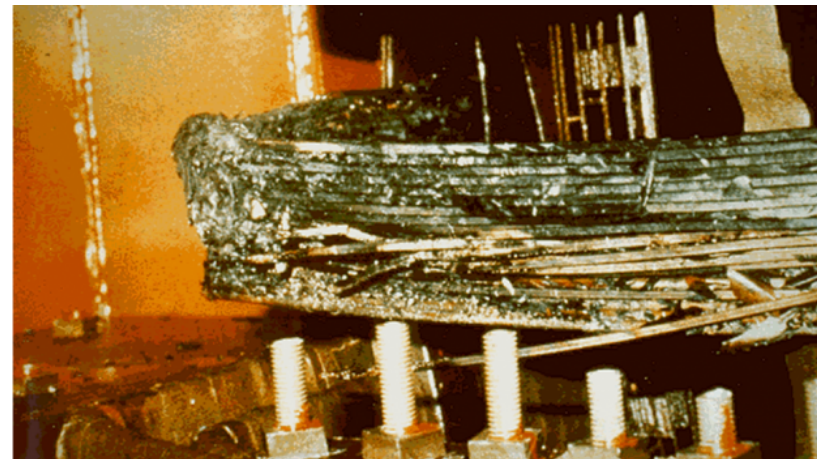


1989 March Storms

- Space shuttle sensor issues.
- Public radio signal disruption.
- Montreal international airport temporarily paralysed.
- Power blackout in Quebec for 9 hours, affecting 6 million people.

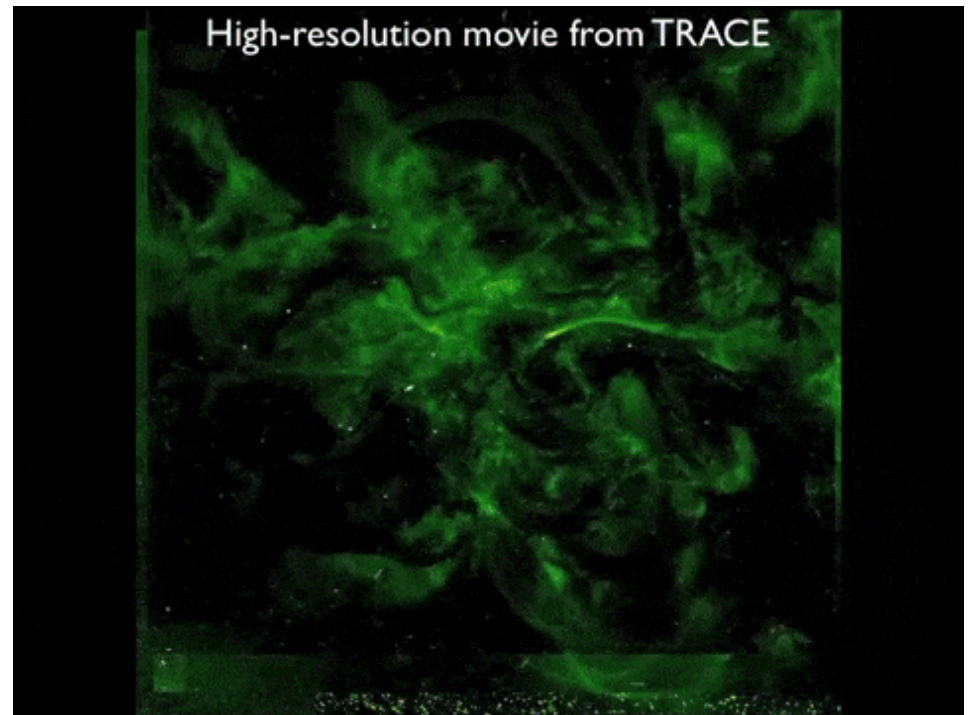


NOAA/SWPC



2003 Halloween Storms

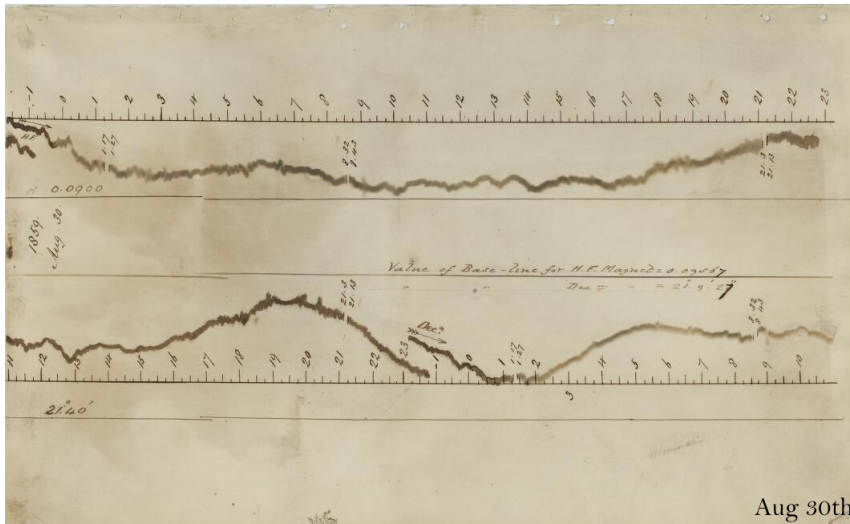
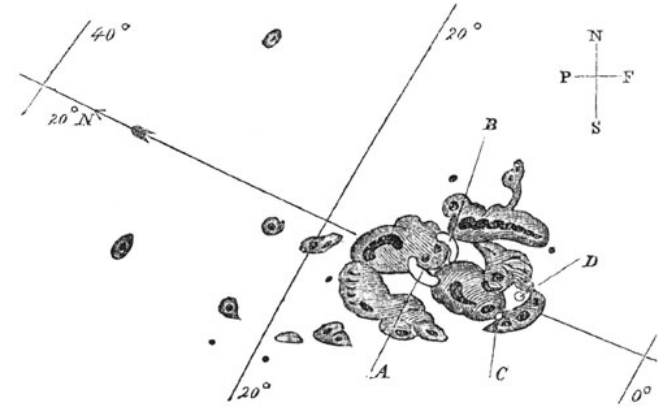
- Japanese satellite was permanently damaged.
- Aircraft forced to land in Greenland due to communications blackout and excess radiation exposure.
- British Airways flew at lower altitudes.
- Other US flights re-routed or restricted.
- Air traffic control kept transatlantic lights on more southerly routes.
- Hour-long power outage in Sweden.
- Compass north in the UK changed temporarily by five degrees in just six minutes.



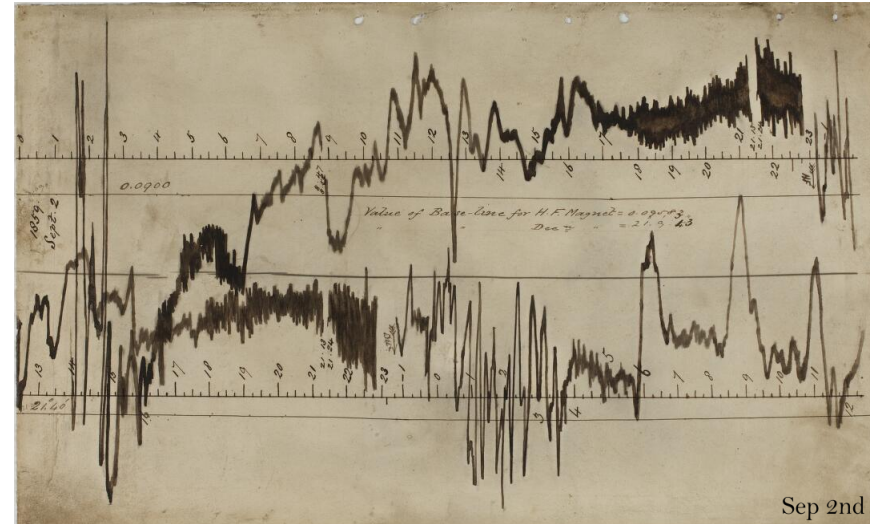
thesuntoday.org

1859 Carrington Event

- Telegraph systems failed across Europe and North America.
- Stock prices not available in Dublin from London for 24 hours.
- Widespread aurora (as far south as Caribbean and north as Queensland).
- Probability: ~ 1 in 100 years.



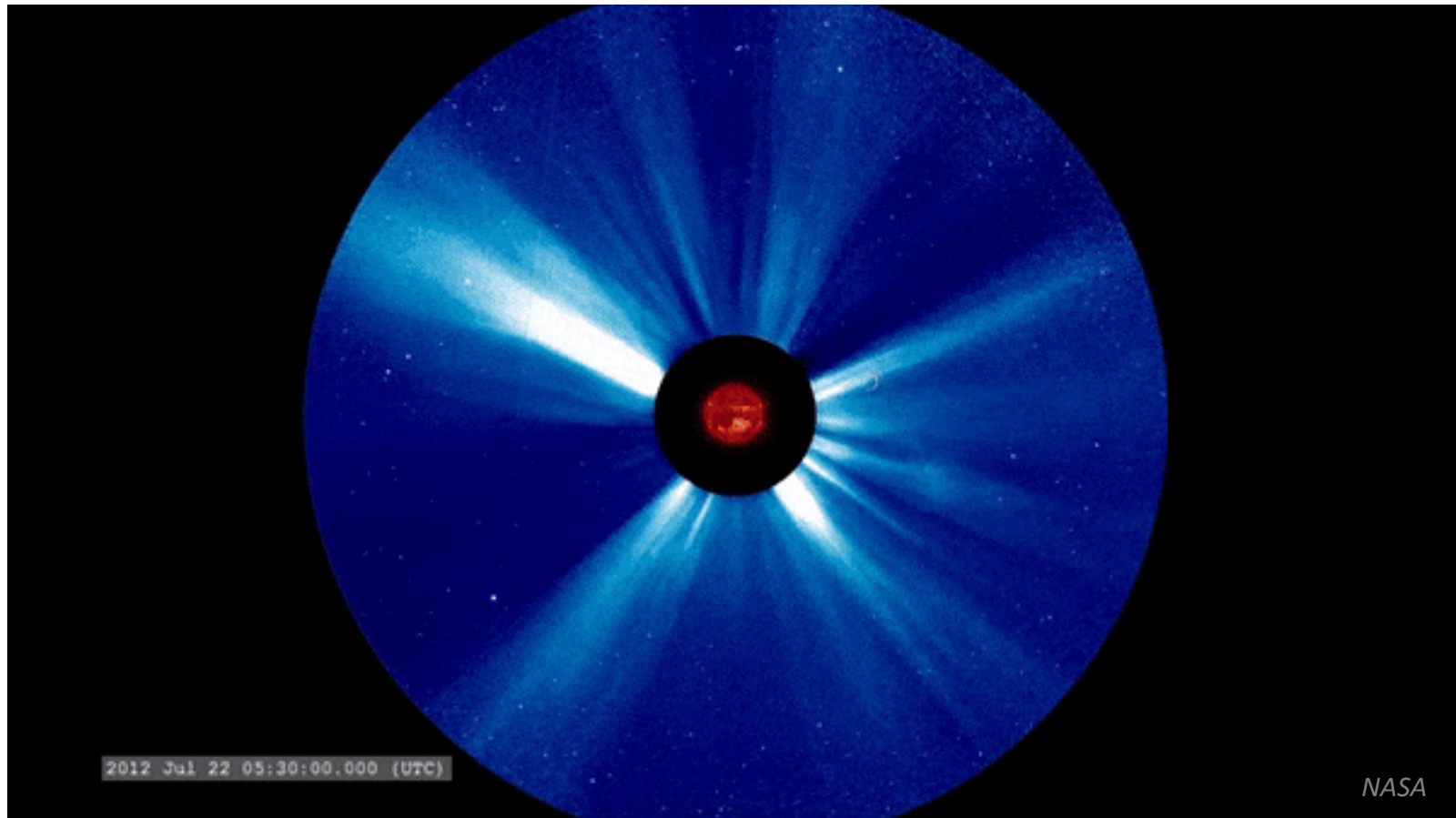
Aug 30th



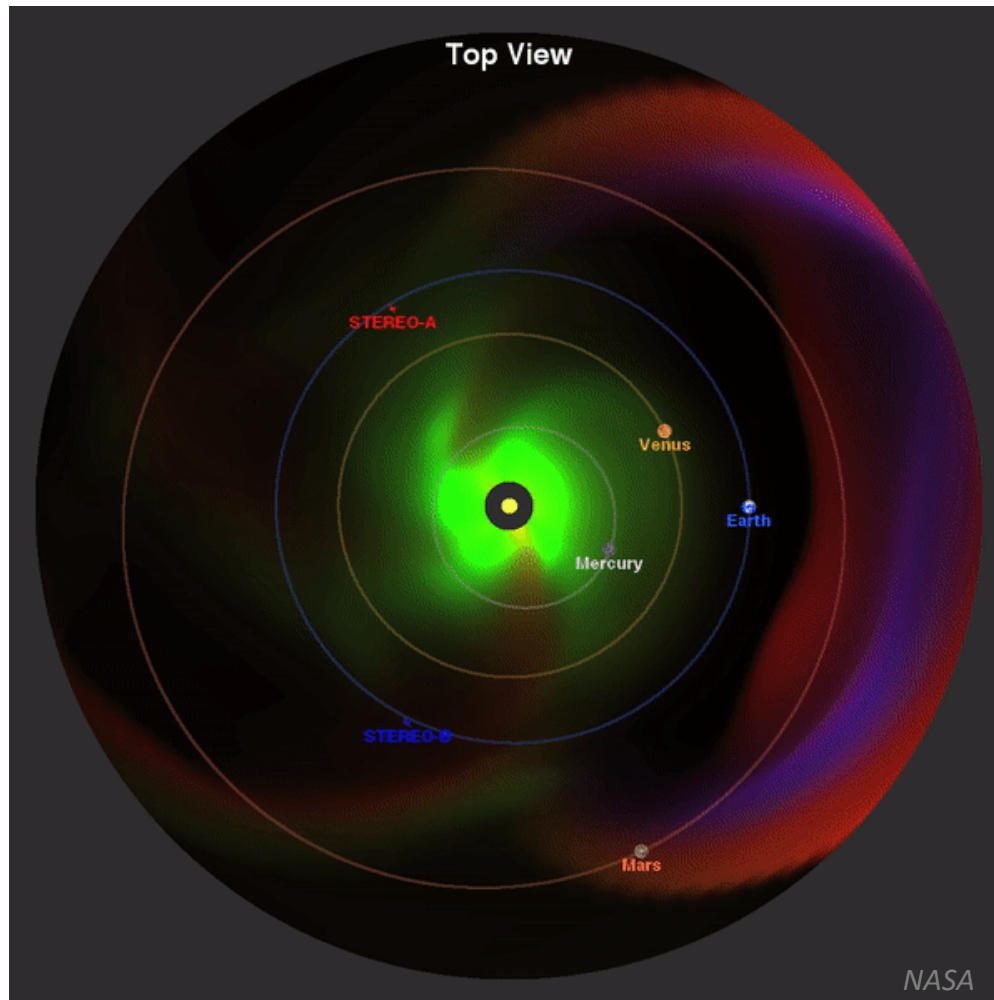
Sep 2nd

BGS

2012: A Near Miss



2012: A Near Miss



Event	DST
Normal	-50nT
1989	-600nT
1859	-1750nT
2012	-1200nT



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Mitigation

Impact Studies



US National
Academy
of Science
2008



Lloyds
2011



Royal
Academy of
Engineering
2013



AIG
2016

Operational Centres

Monitoring and Forecasting

 SWS (Australia)	 NICT (Japan)
 KSO (Austria)	 KSWC (Republic of Korea)
 SIDC (Belgium)	 SCIEMEX (Mexico)
 EMBRACE (Brazil)	 SRC (Poland)
 CSWFC (Canada)	 IAG (Russia)
 SEPC (China)	 SANSA (South Africa)
 SAPC (China)	 LSWC (Sweden)
 IAP (Czech Republic)	 MOSWOC (UK)
 NPL (India)	 SWPC (USA)
 SWIFtS (Indonesia)	 ESA (Noordwijk)

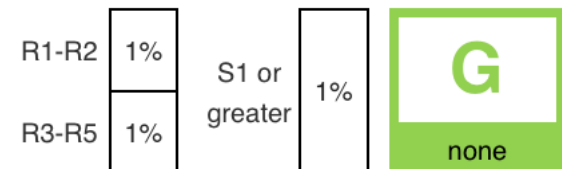
24-Hour Observed Maximums



Latest Observed



Predicted 2017-02-16 UTC

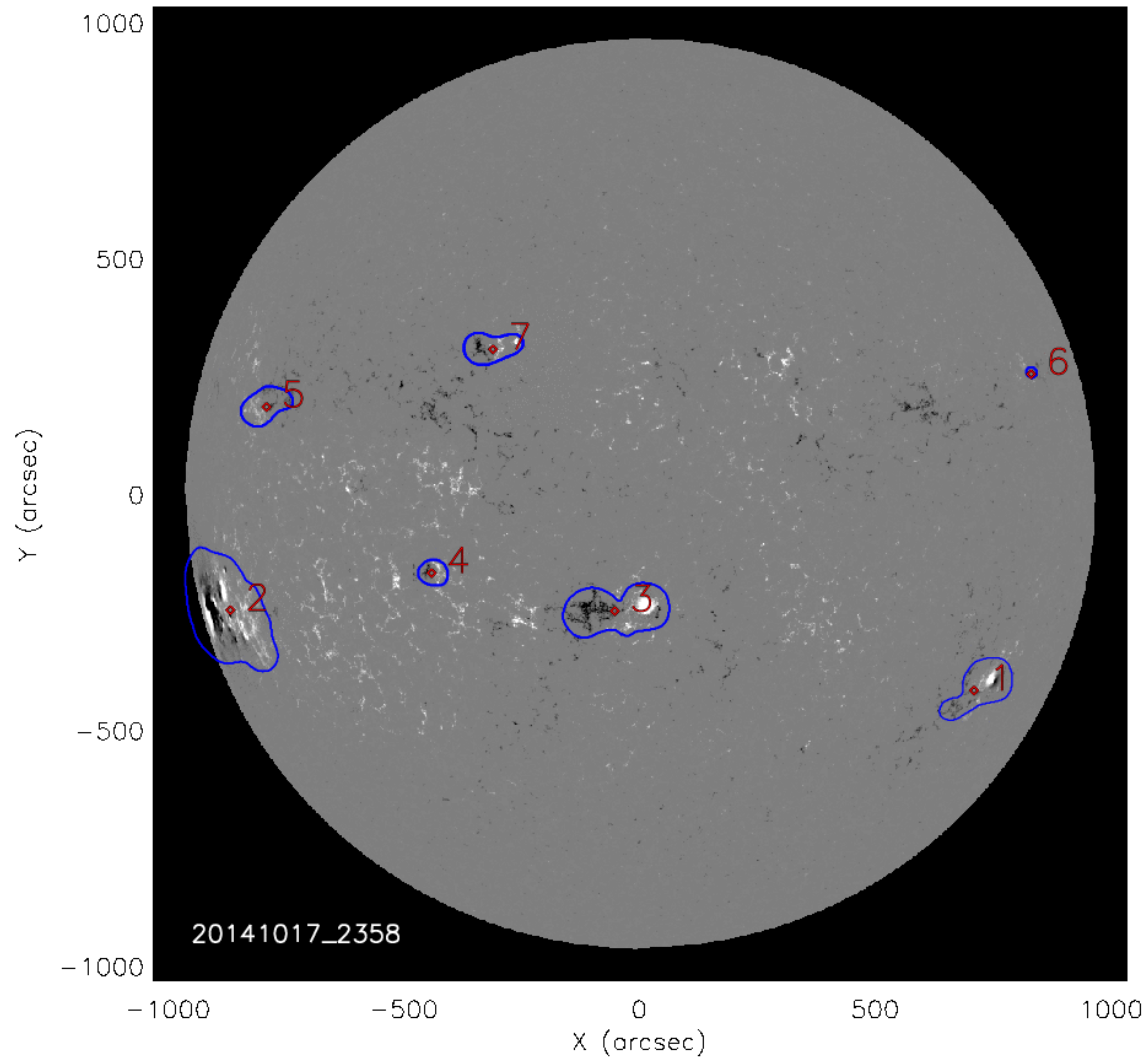


NOAA/SWPC

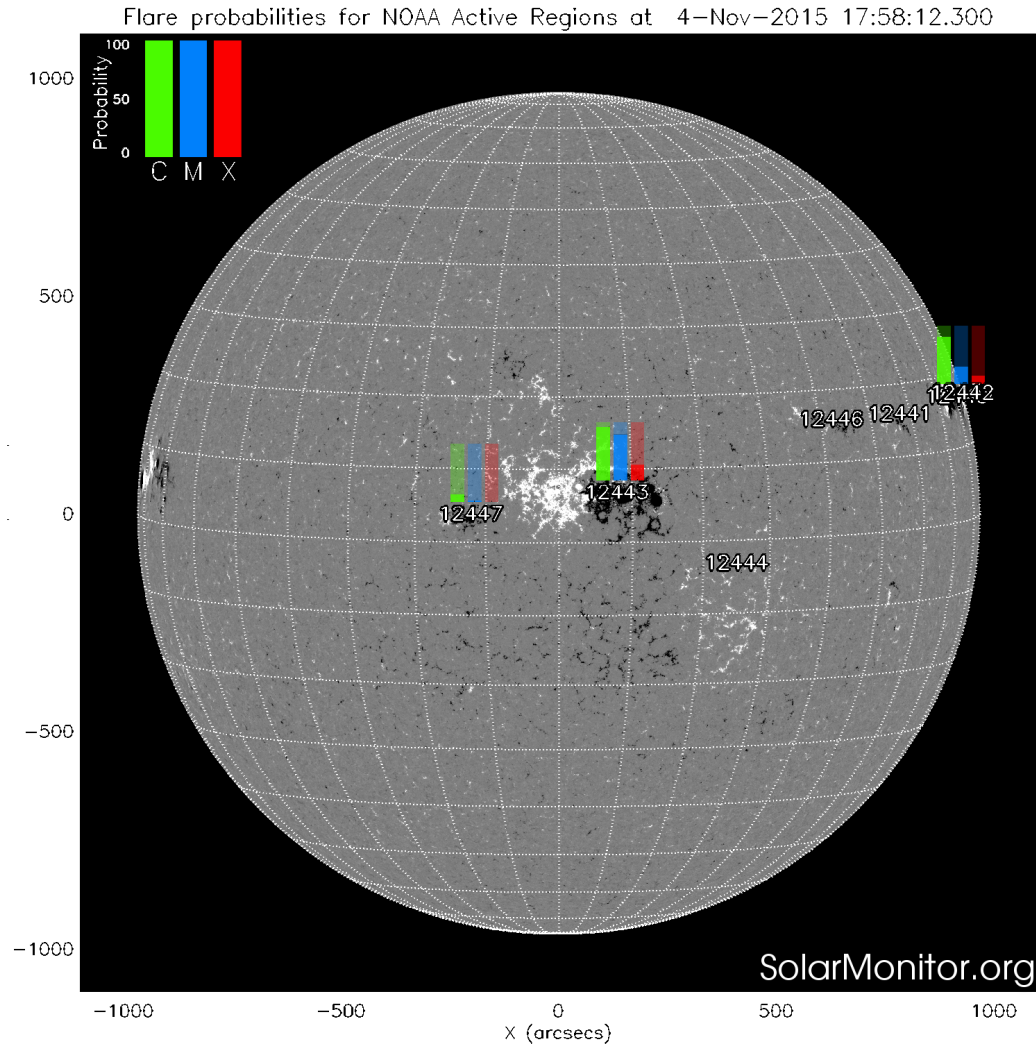
International Space Environment Service, spaceweather.org

Active Region Evolution

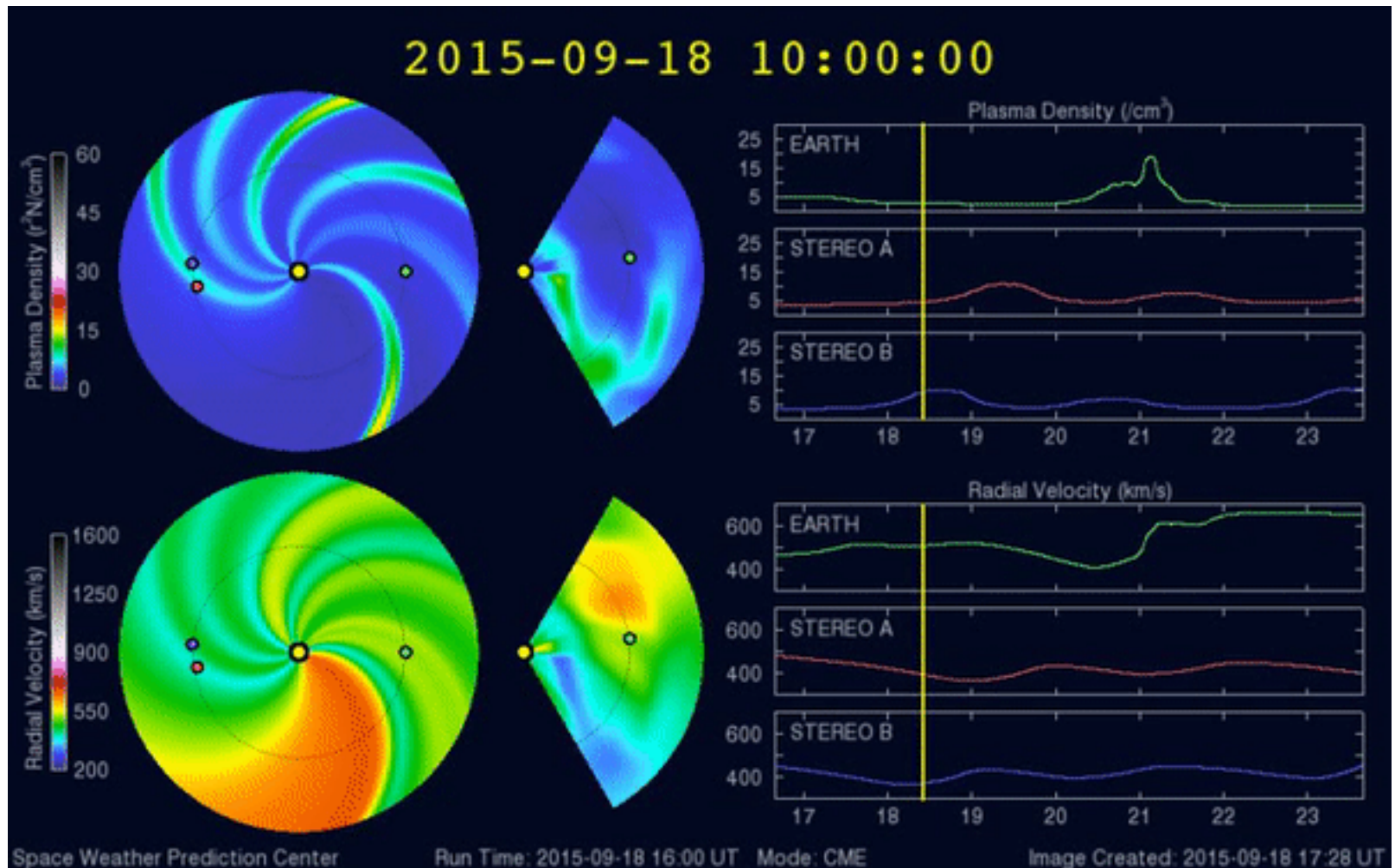
Solar Monitor Active Region Tracker



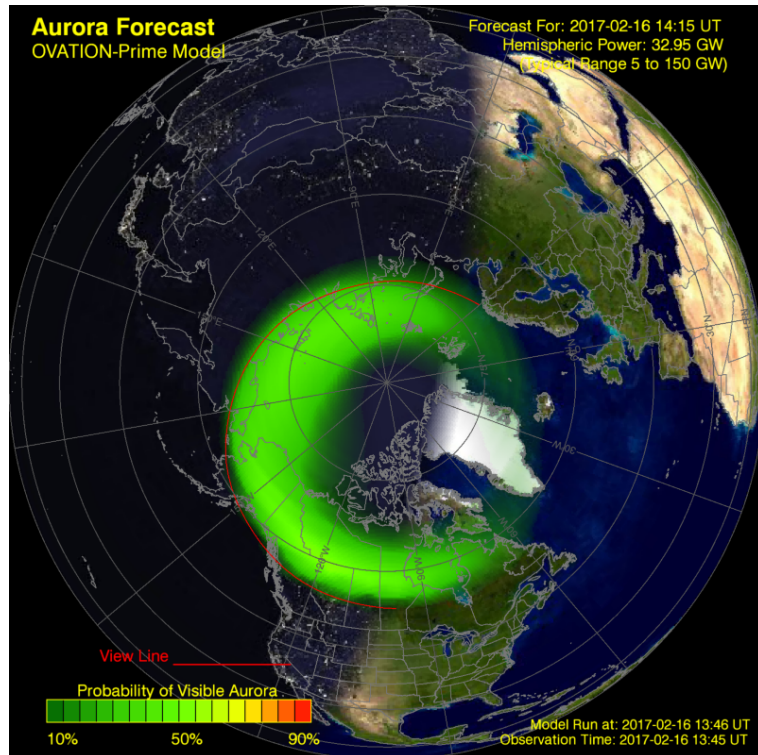
Flare Prediction



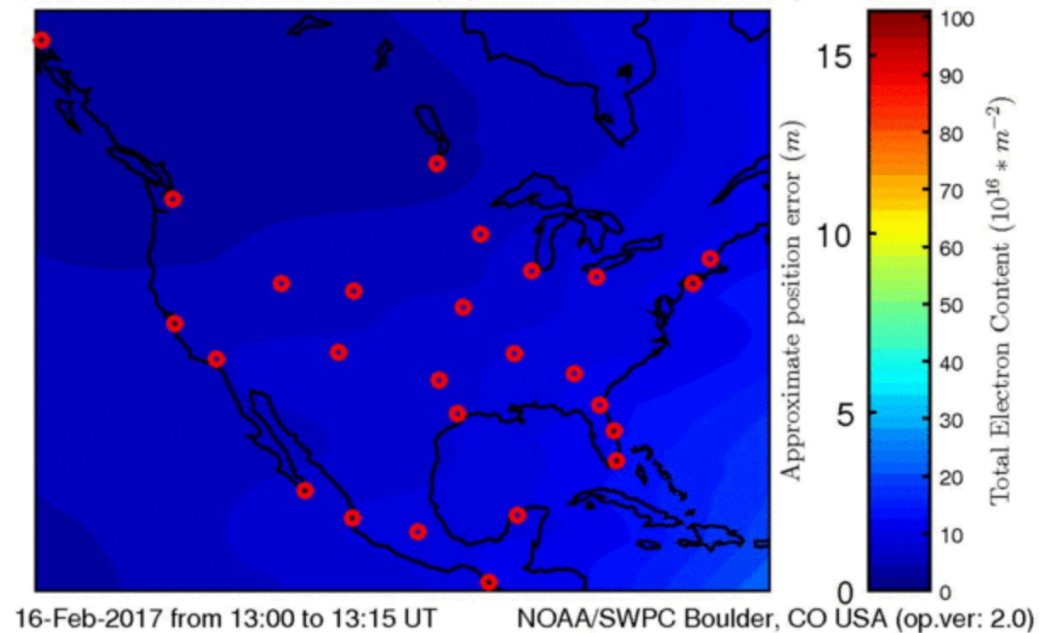
CME Arrival Prediction



Earth Impact Forecasts



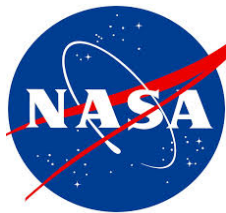
Approximate L1 Position Error (m) and TECu ($10^{16} * m^{-2}$)



Research

TCD Solar and Space Weather Research Group

- 4 PhD Students and 6 Postdoctoral Research Fellows
- Operate RosseObservatory.ie and building LOFAR.ie
- Run SolarMonitor.org
- Member of multiple ESA and NASA spacecraft teams.
- Working with:





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Thank you!

