Space Weather and HF Propagation

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22 February 2018

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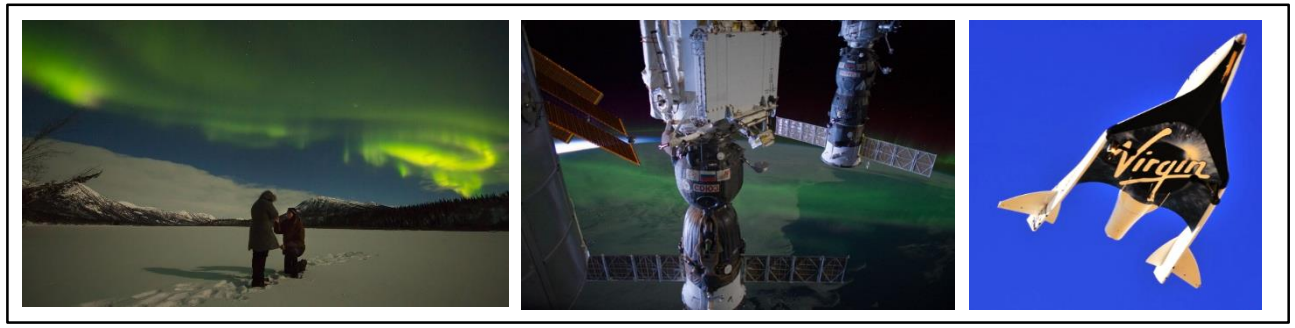
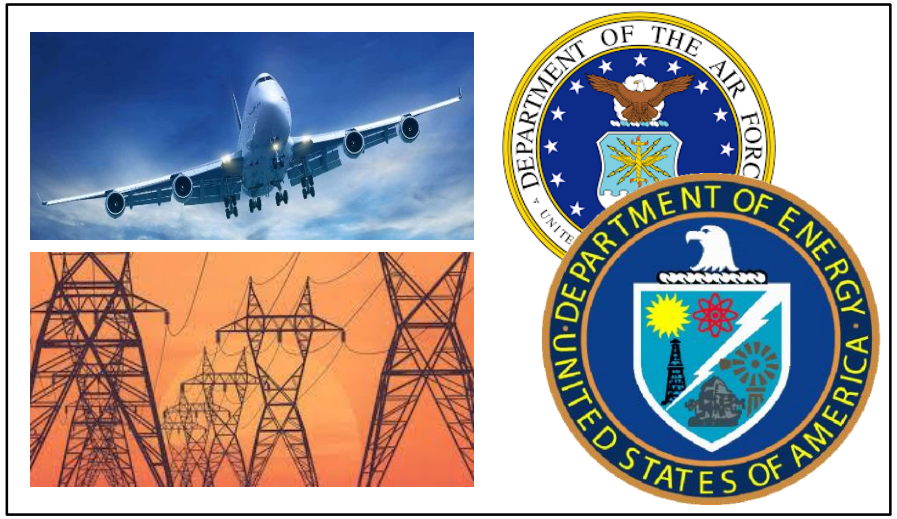
Why Does Space Weather Forecasting Matter?

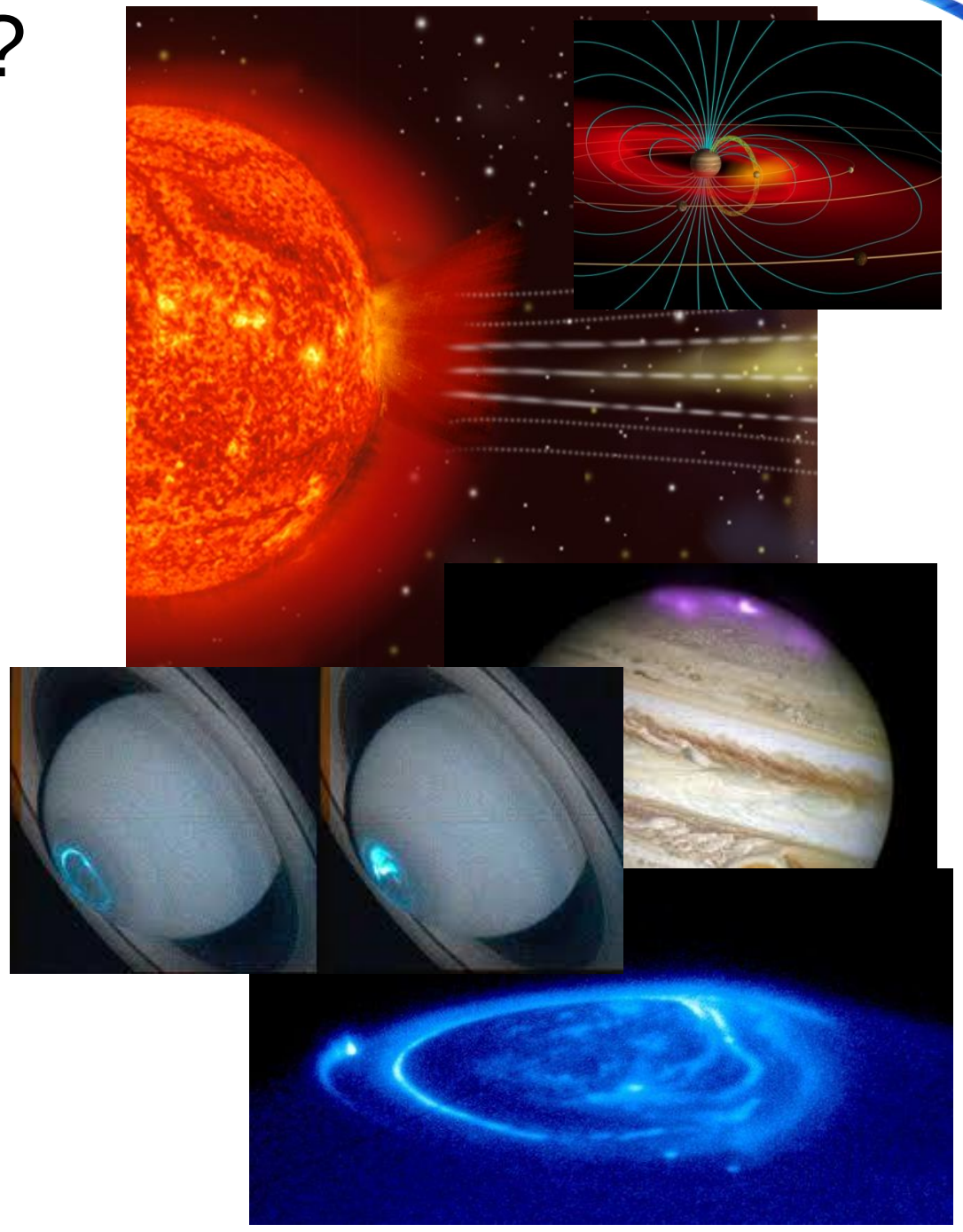




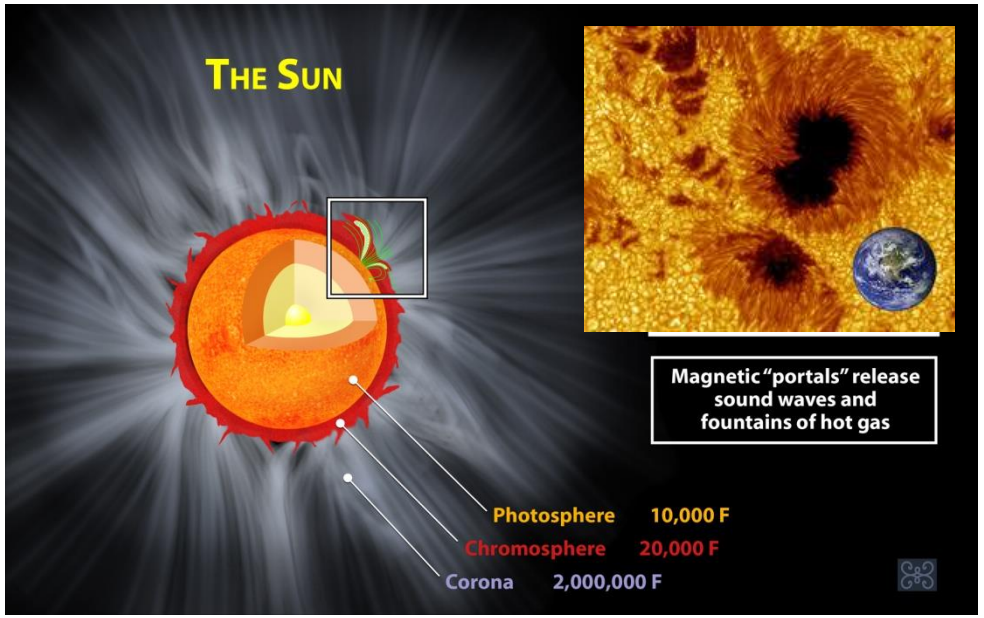
What is Space Weather?

Essentially Space Weather is:

- A planet's interaction with its host star and the surrounding space environment
- More generally, it occurs at planets, moons, comets, asteroids, and other celestial bodies in the universe
- We see aurora at planets
  - Jupiter, Saturn, Uranus, and Mars
- We see effects at Moons
  - Io, Europa, Ganymede, and Titan
- Main effects are **Sun-driven**
- Other sources of space weather
  - Cosmic rays
  - Micrometeroids & interstellar dust
  - Space junk



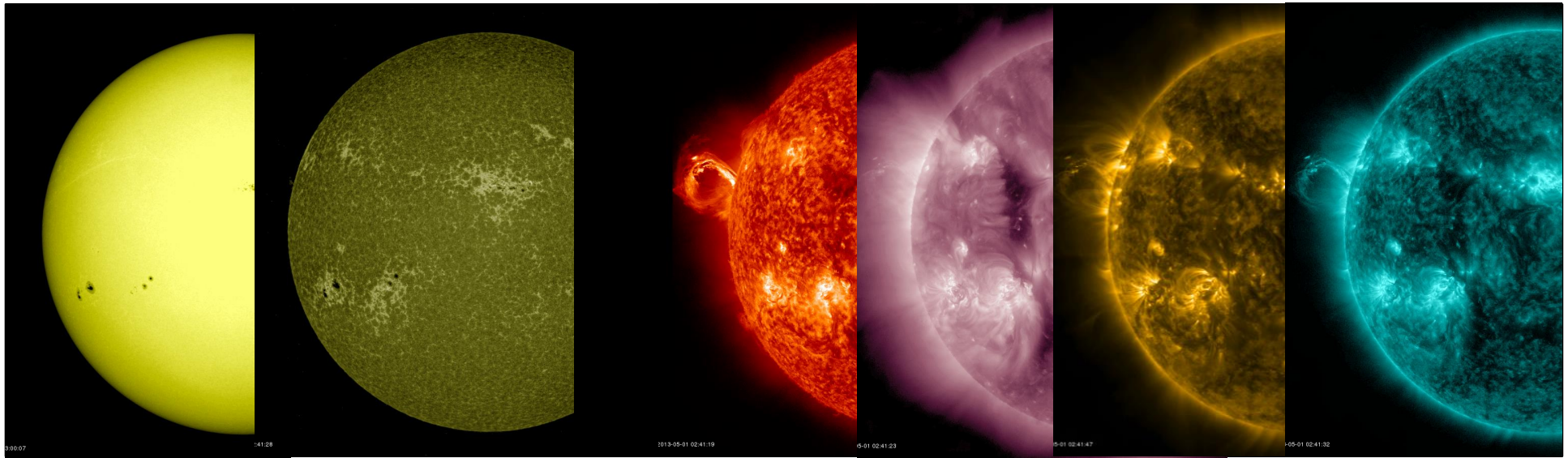
Our Star



- Giant fusion reactor: Drives Space Weather
- Energy output in the form of:
  - Electromagnetic radiation (from X-rays through radio)
  - Solar wind plasma & magnetic fields
  - Flares
  - Solar Energetic Particles (SEPs) (aka solar radiation storms)
  - Coronal Mass Ejections (CMEs)

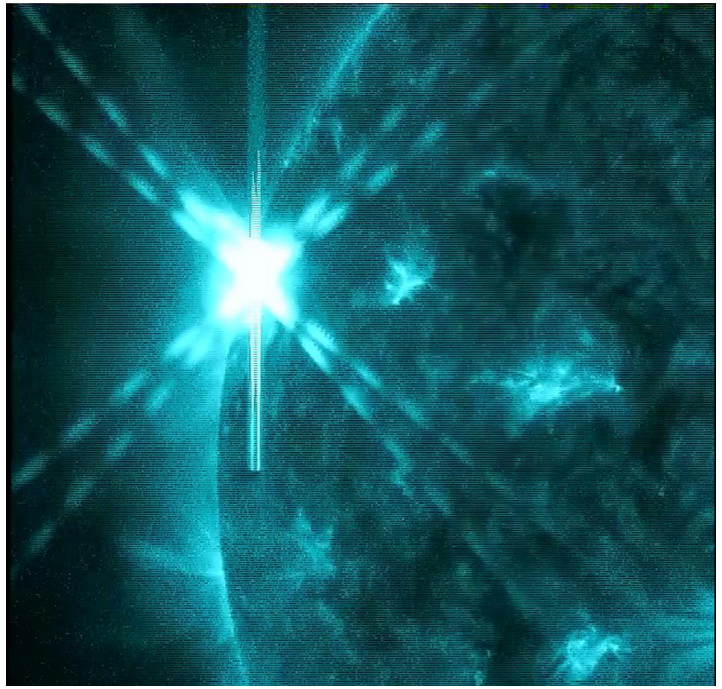
What do Space Telescopes See?

5700 °C → 6.3 Million °C

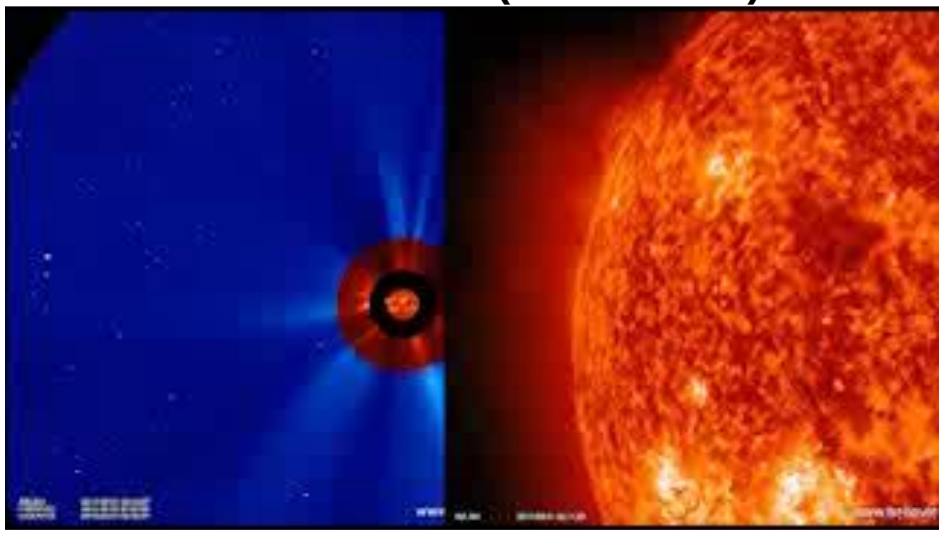


Four Basic Types of Solar Phenomena Affecting Earth

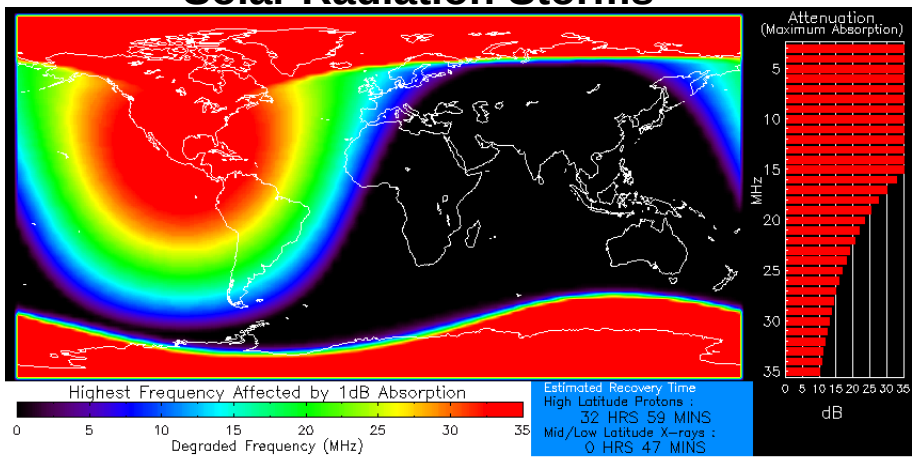
Solar Flares



Solar Storms (a.k.a. CMEs)



Solar Radiation Storms



Moderate X-ray flux
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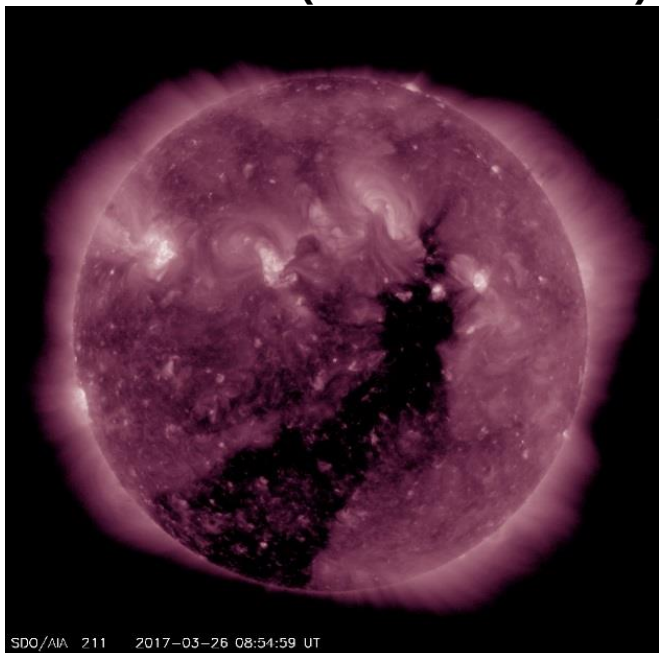
Moderate Proton Flux
NOAA/SWPC Boulder, CO USA

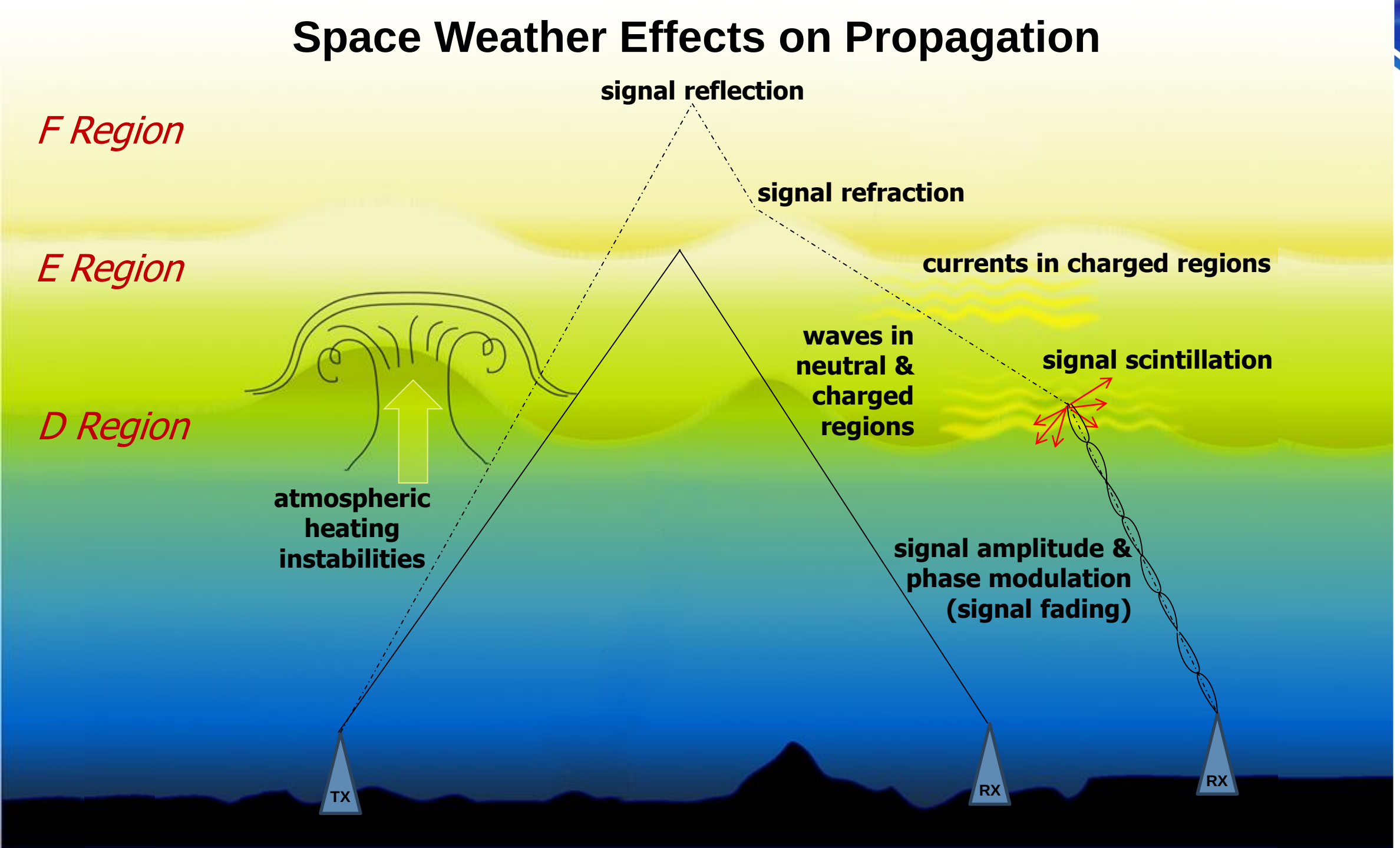
Coronal Holes (Fast Solar Wind)



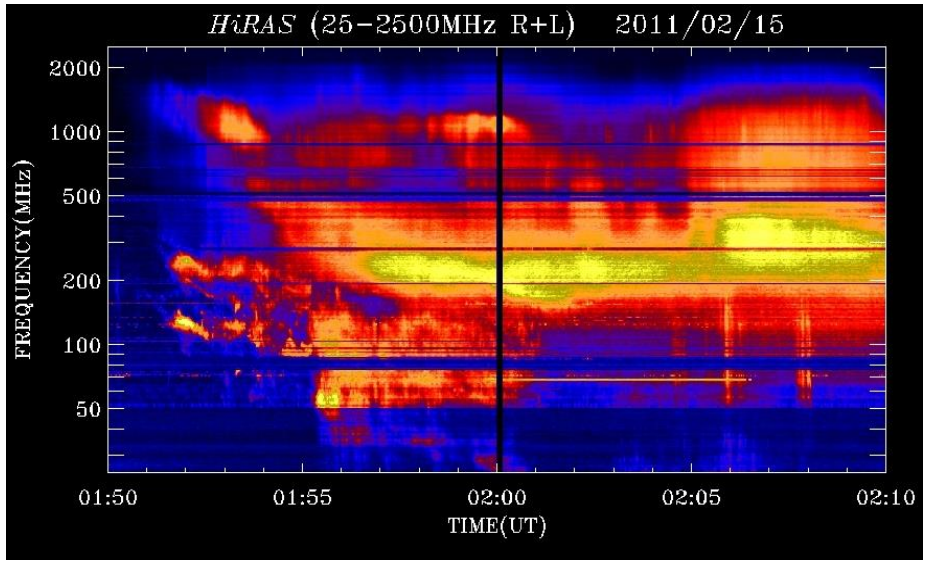
What is the Ionosphere?

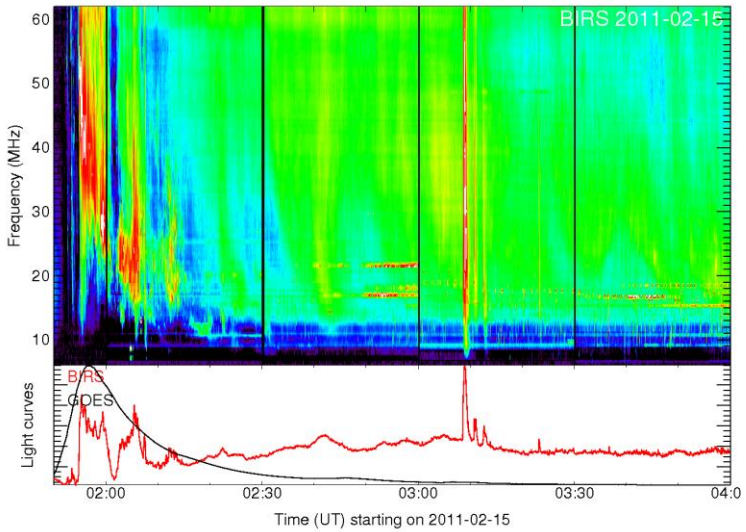
- Ionosphere is a charged plasma layer above the atmosphere comprised of ions and electrons
- It would be neutral but it gets charged from exposure mainly to the Sun’s UV radiation
- This charged nature facilitates radio propagation
- Solar phenomena affect the ionosphere in dramatic ways

Space Weather Effects on Propagation



Space Weather Audible Interference





Solar flare: Solar radio bursts cause radio blackouts over a wide frequency range
https://www.wired.com/2013/02/radio-solar-outburst/

Dawn Chorus: Radio Waves due to energetic particles in the magnetosphere
https://www.nasa.gov/mission_pages/rbsp/news/emfisis-chorus.html#.VVWFy_lVikp

Sferics and Tweeks: Radio waves caused by lightning nearby
http://www.spaceweather.com/glossary/inspire.html

Whistlers: Radio waves caused by lightning far away
http://www.spaceweather.com/glossary/inspire.html

…So how bad can Space Weather be?

3 Categories

- Geomagnetic Storms (CMEs)
- Solar Radiation Storms (Particle Events)
- Radio Blackouts (Solar Flares)

http://www.swpc.noaa.gov/noaa-scales-explanation

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
Solar Radiation Storms				
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible. Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 10 chest x-rays) is possible. Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in commercial jets at high latitudes may receive low-level radiation exposure (approximately 1 chest x-ray). Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: none. Satellite operations: infrequent single-event upsets possible. Other systems: small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

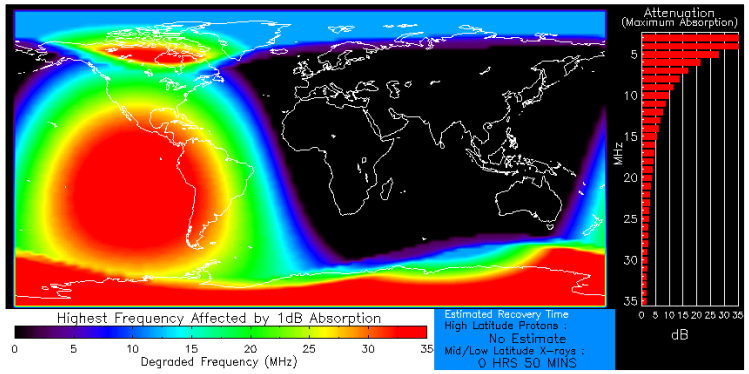
* Flux levels are 5 minute averages. Flux in particles·s^{-1}·ster^{-1}·cm^{-2}. Based on this measure, but other physical measures are also considered.
** These events can last more than one day.

			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
Radio Blackouts				
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

Ground & Space Communications Disruptions

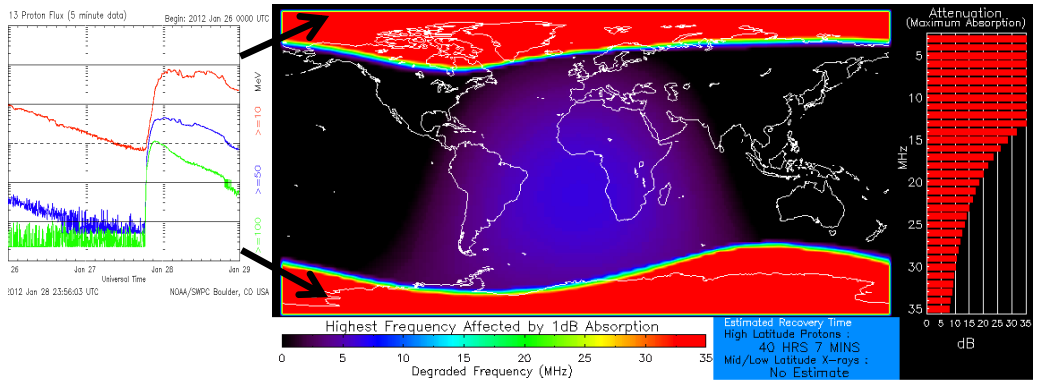
X2 Solar Flare (27 Jan 2012)



Moderate X-ray flux
Product Valid At : 2012-01-27 19:00 UTC

Normal Proton Background
NOAA/SWPC Boulder, CO USA

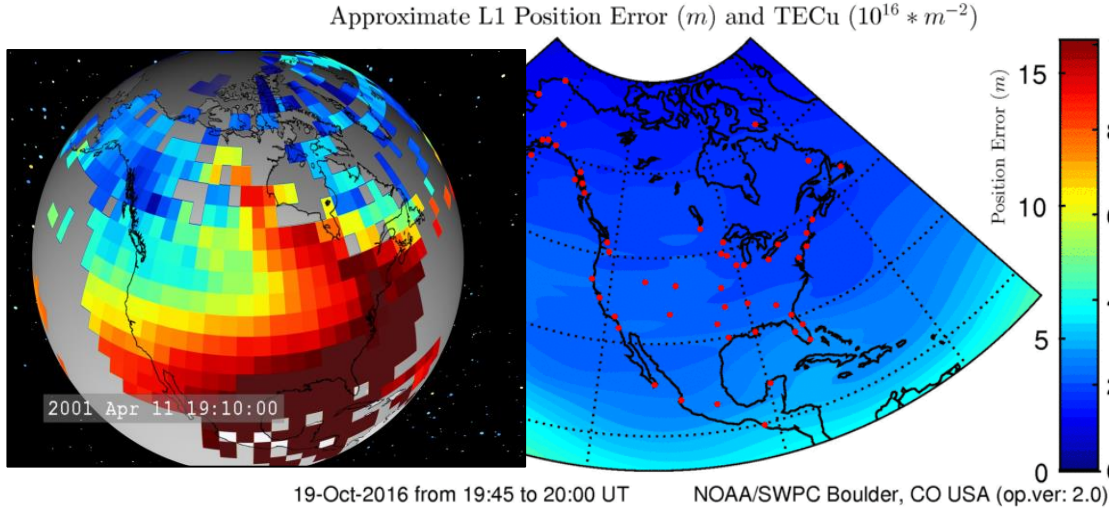
Radiation Storm (23-25 Jan 2012)



Normal X-ray Background
Product Valid At : 2012-01-28 12:20 UTC

Moderate Proton Flux
NOAA/SWPC Boulder, CO USA

GPS & Location-Based Service Disruptions

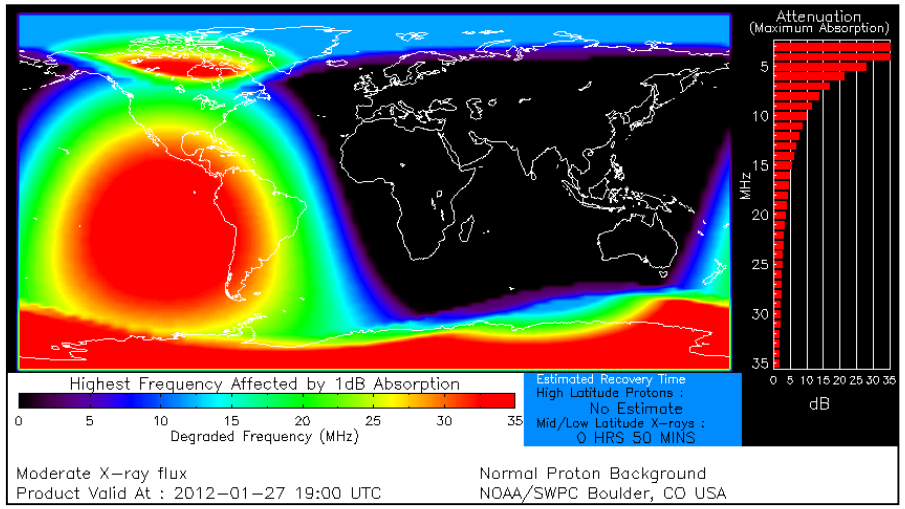


Reprinted courtesy of NOAA

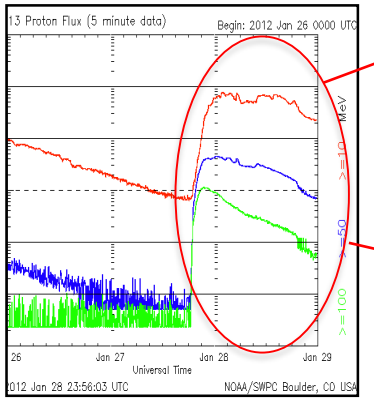
HF Band Communications Disruptions

FAA Radio Communications Center reported that the CEP (Central East Pacific) and CWP (Central West Pacific) regions were:
"impacted severely by solar activity between 1830Z and 1930Z on 27 Jan due to the R3 solar flare radio blackout. Thirteen requests were received from ATC for overdue position reports."

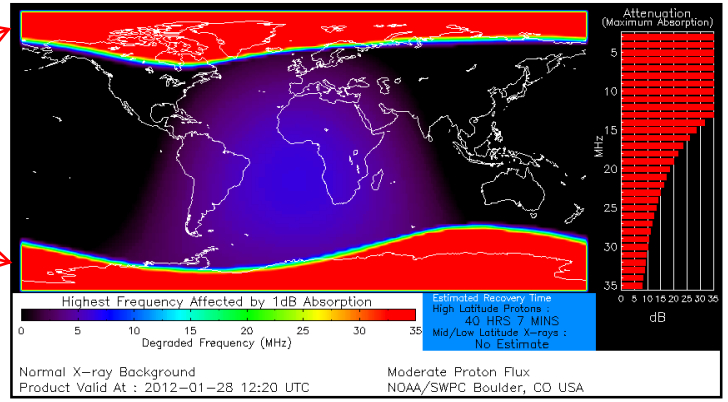
X2 Solar Flare (27 Jan 2012)



Several polar flights altered due to S3 Radiation Storm (23-25 Jan)



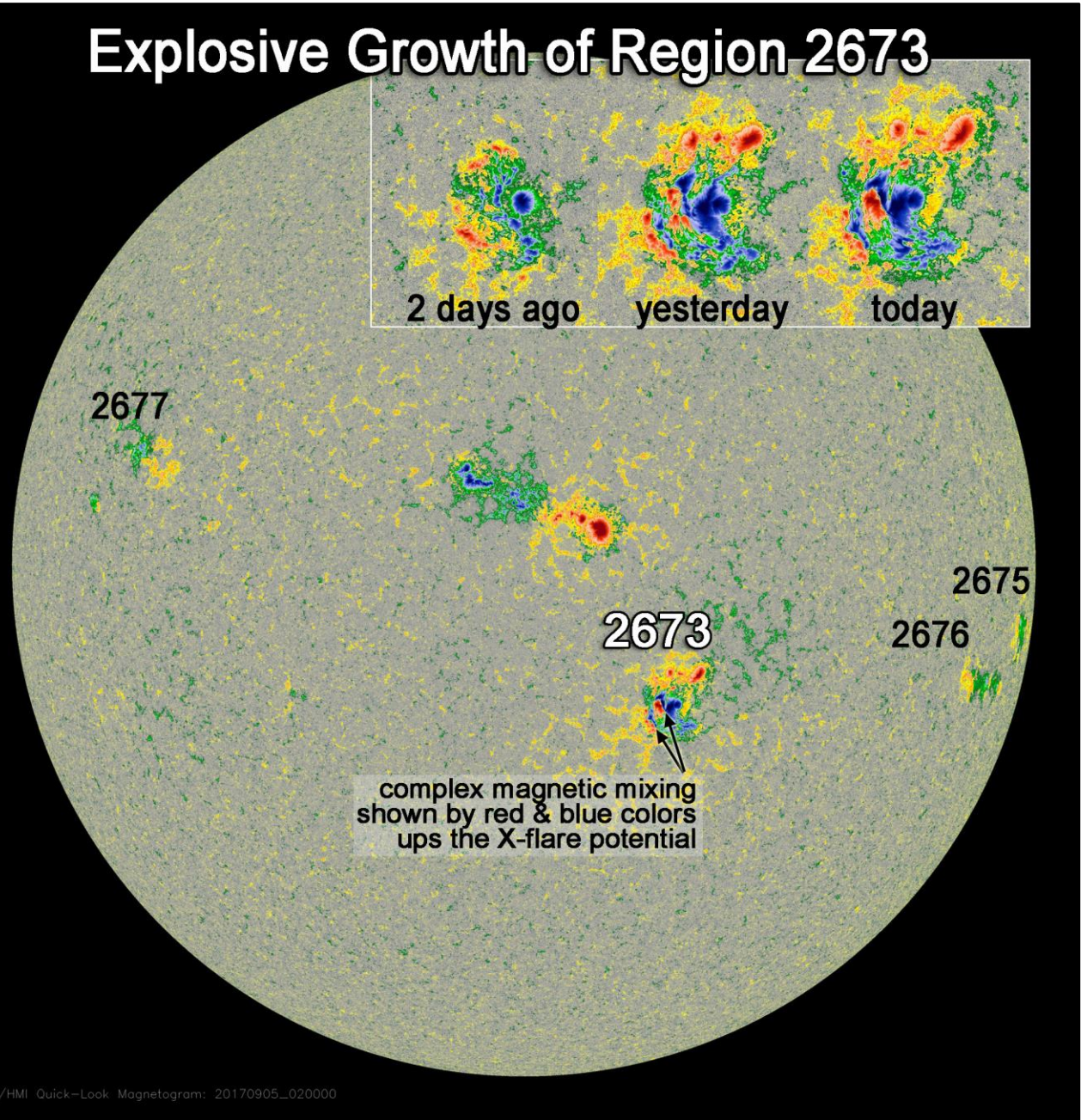
Radiation Storm (23-25 Jan 2012)



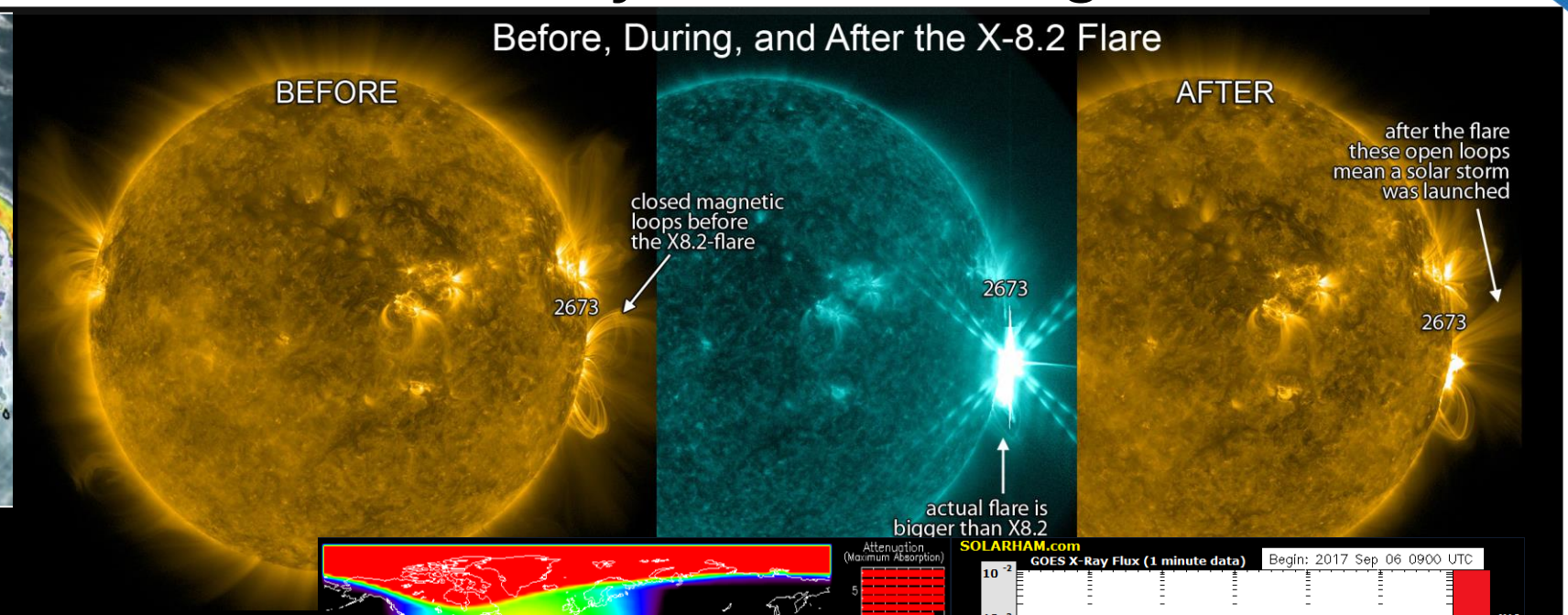
Major airline report: "…some of our polar flights (but not all) have reported HF comm outages/issues over the past 3 nights."

Reprinted courtesy of NOAA

Perfect Storm: Hurricane Harvey, Irma, & Region 2673

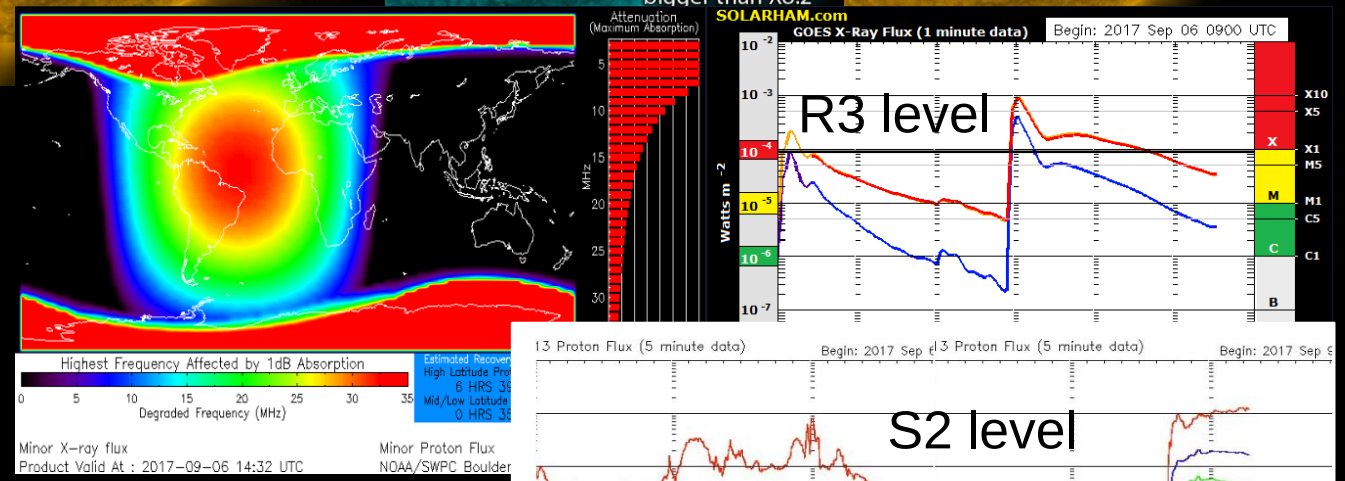


Perfect Storm: Hurricane Harvey, Irma, & Region 2673

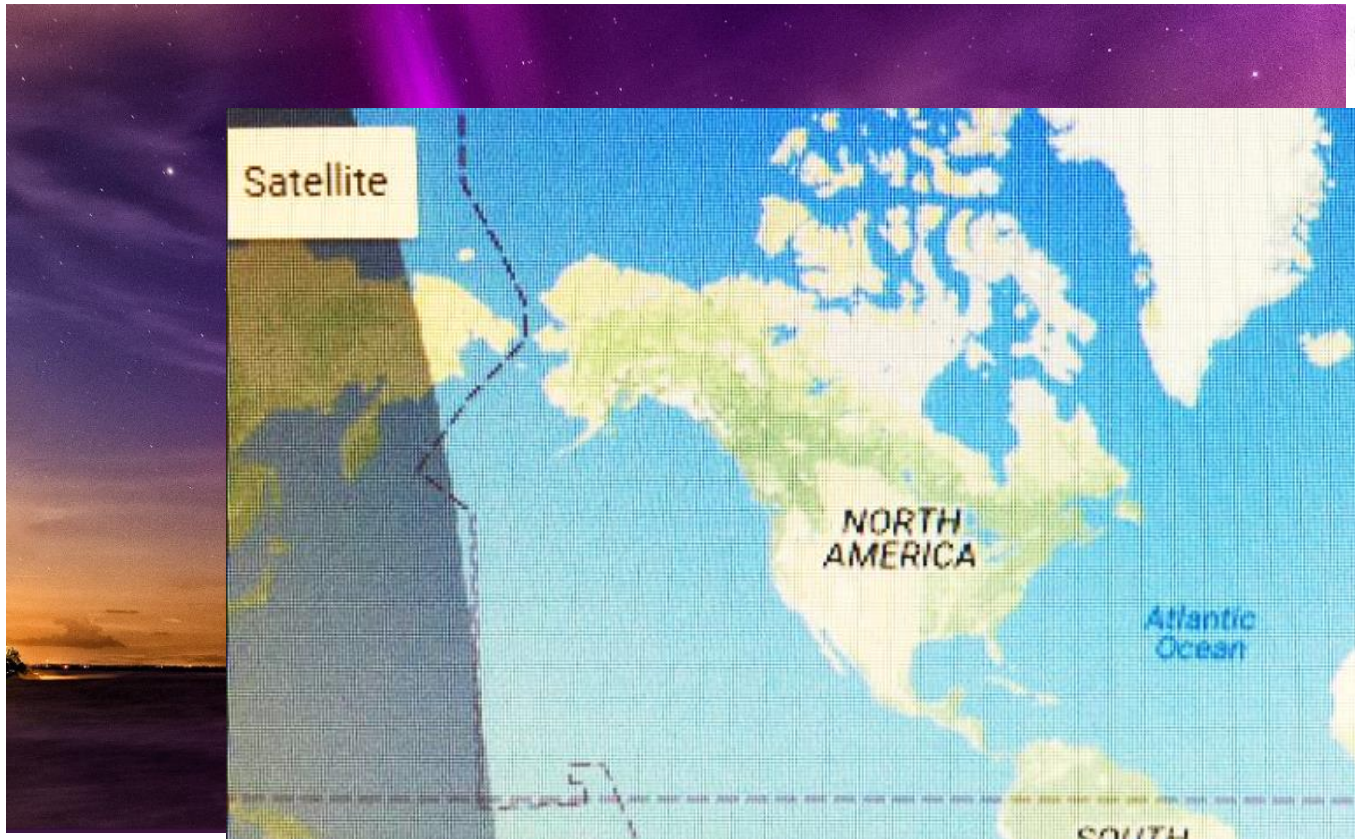


Region 2673 launched in a single week (Sep 3 – Sep 10):

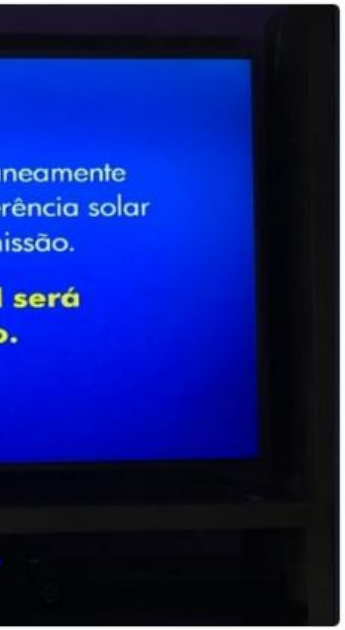
- 4 X-class flares
  (R3 - R4 level radio blackout)
- 25 M-class flares
  (R1 - R2 level radio blackout)
- 2 Solar Radiation storms (S2 - S3 level)
- 2 Geomagnetic storms (G4 level)



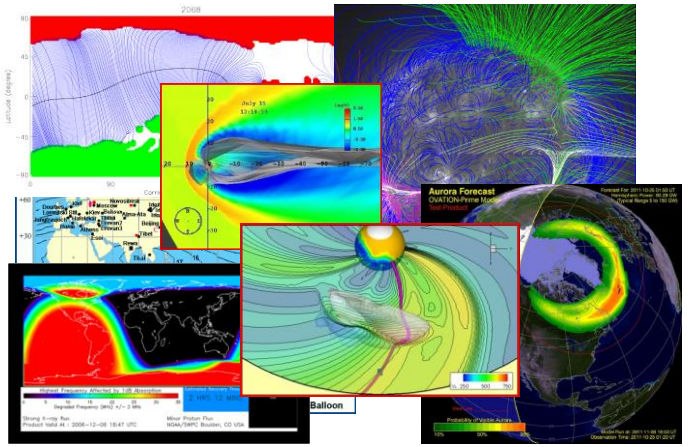
Perfect Storm: Hurricane Harvey, Irma, & Region 2673



sky hdtv
@skyhdtvbrasil
Following



Space Weather Forecasting: A Return to the Sixties



Space Weather Prediction Centers

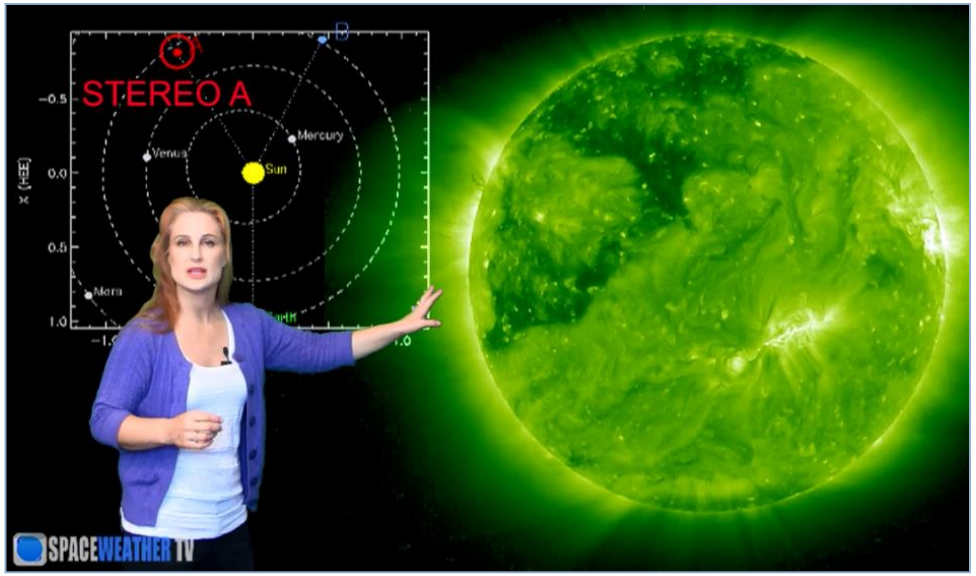
- Developed mainly as a response to super storms
- Models that predict solar fields, CME transit, magnetospheric responses→ solar storm alerts
- Radio blackouts, solar radiation storms→ FAA alerts
- Space & ground telescopes for 24/7 monitoring of Sun
- “Spaceship Earth” networks

~1960

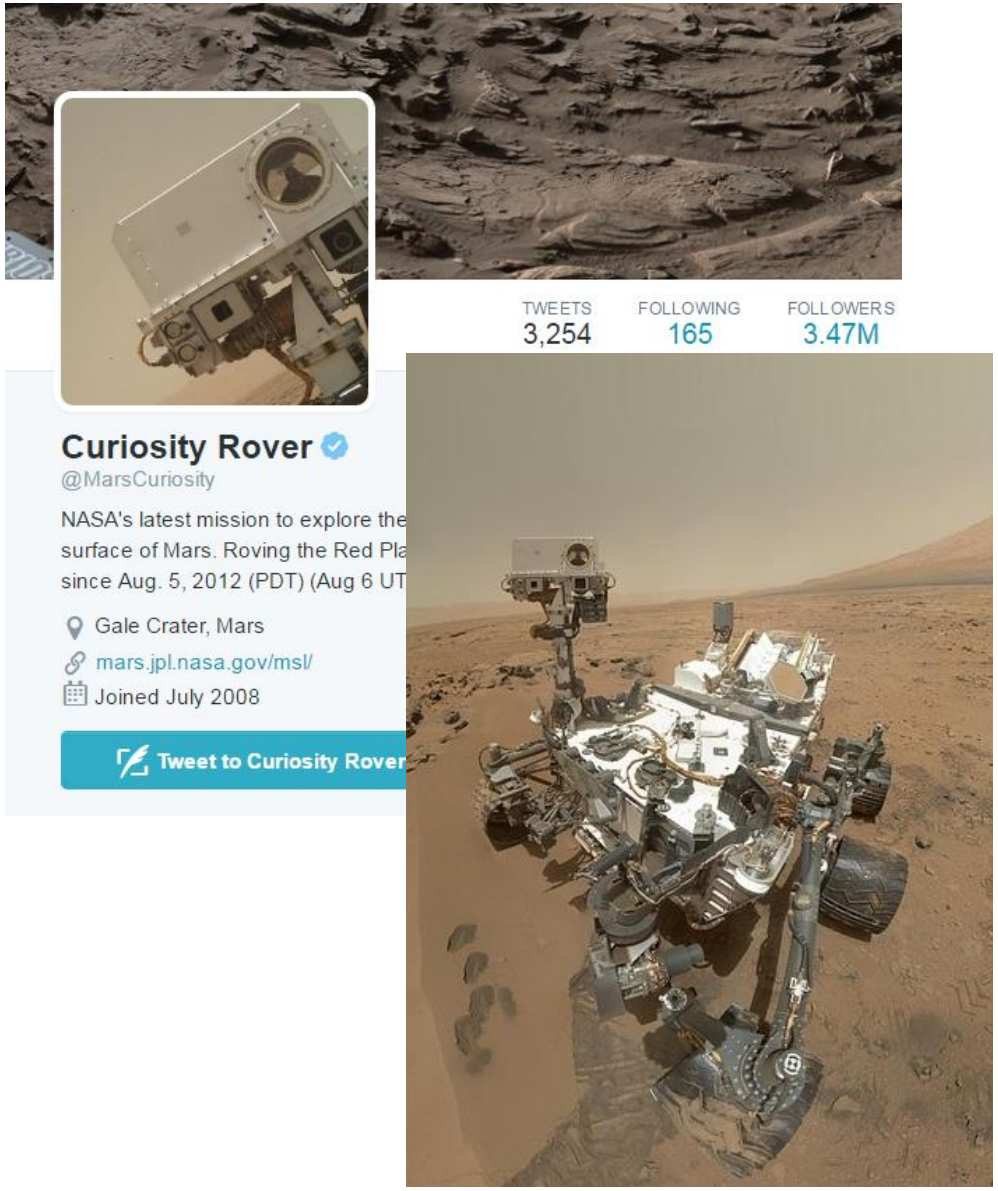
Harry Volkman: Broadcast Meteorologist

Today

Tamitha Skov: Broadcast Space Meteorologist



Future of Space Weather Forecasting: “The Martian”



- Technology savvy Millennials are calling themselves “The Mars Generation”
- Curiosity is the first Martian colonist
- On March 7, 2013 (Martian Sol 207), NASA shut down Curiosity due to an approaching solar storm

- This puts a whole new spin on the movie “*The Martian*”
- How are over-the-horizon communications going to work on Mars?

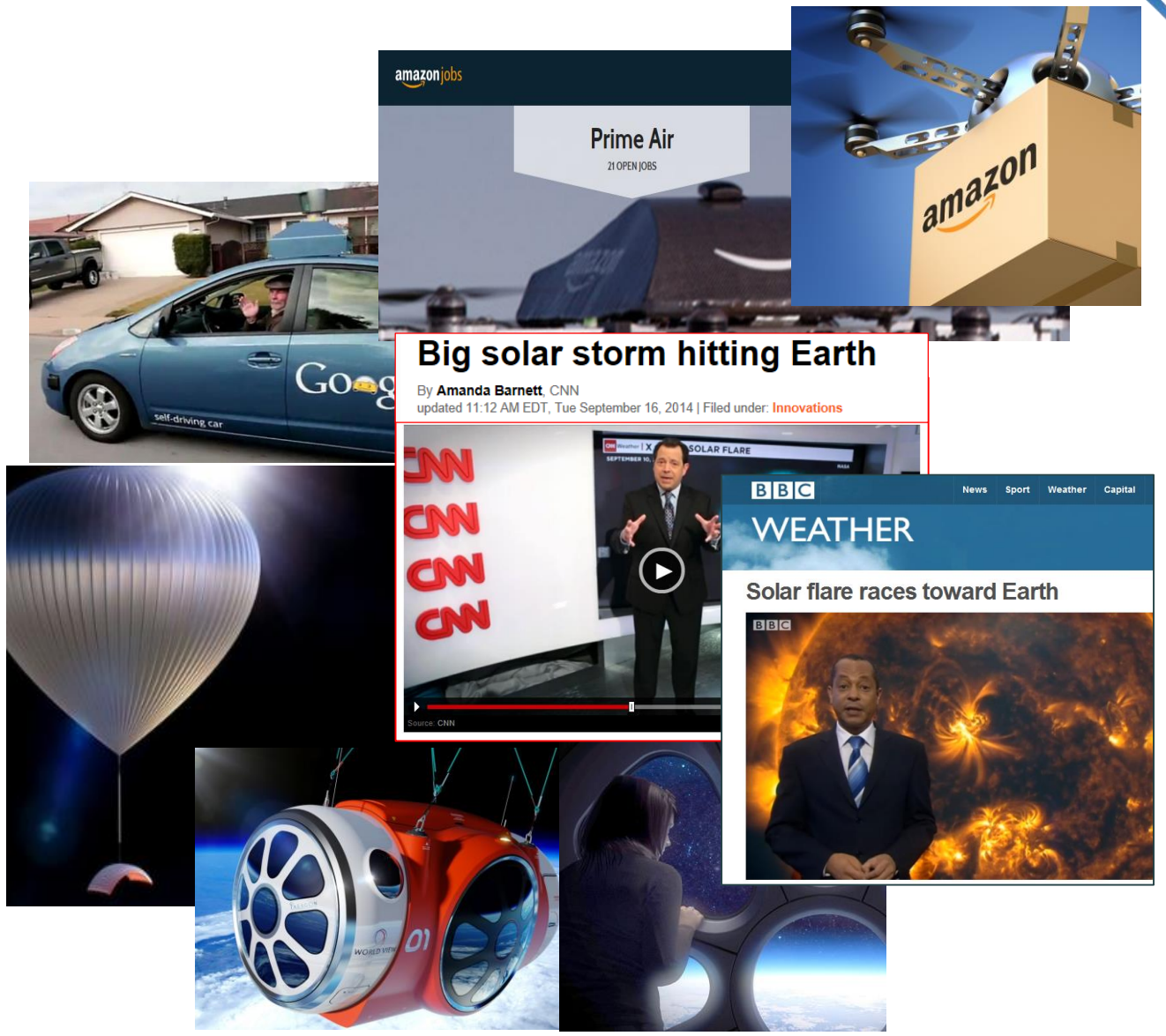
Our Future Relies on Space

Reliance on Space is advancing

- Are we prepared?
- Space weather is like the weather in your own backyard just a little further up.

For more information visit:

- ***SpaceWeatherWoman.com***
- *YouTube for weekly forecast videos: http://www.youtube.com/user/SpWxfx*
- ***@TamithaSkov** on Twitter for daily forecasts and often hourly updates*
- ***Space Weather Woman** on Facebook*
- ***SpaceWeatherWoman@gmail.com***



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