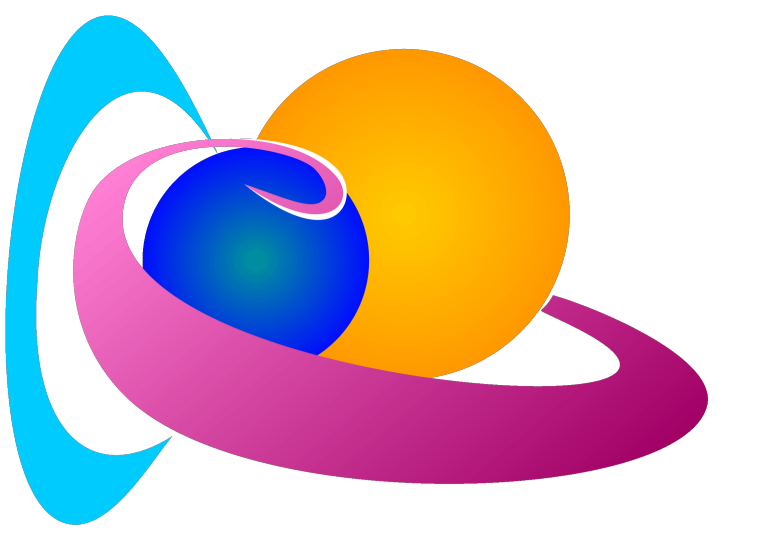


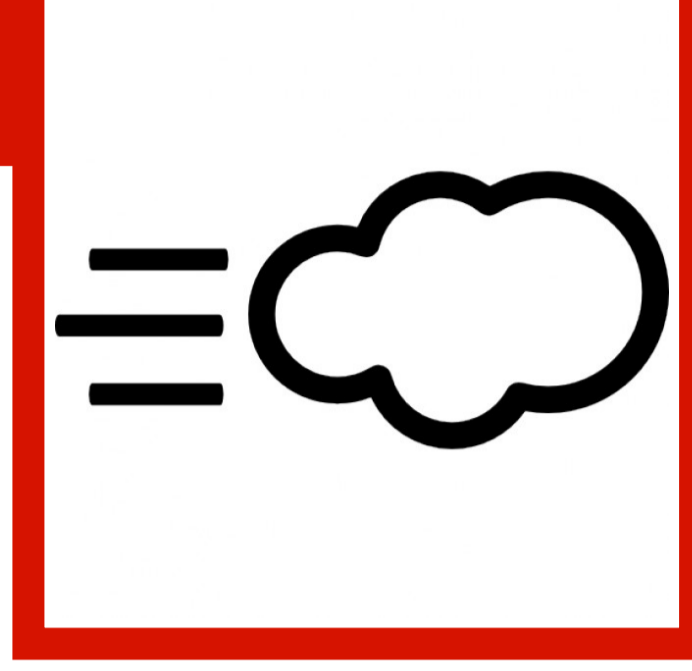
Solar Energy



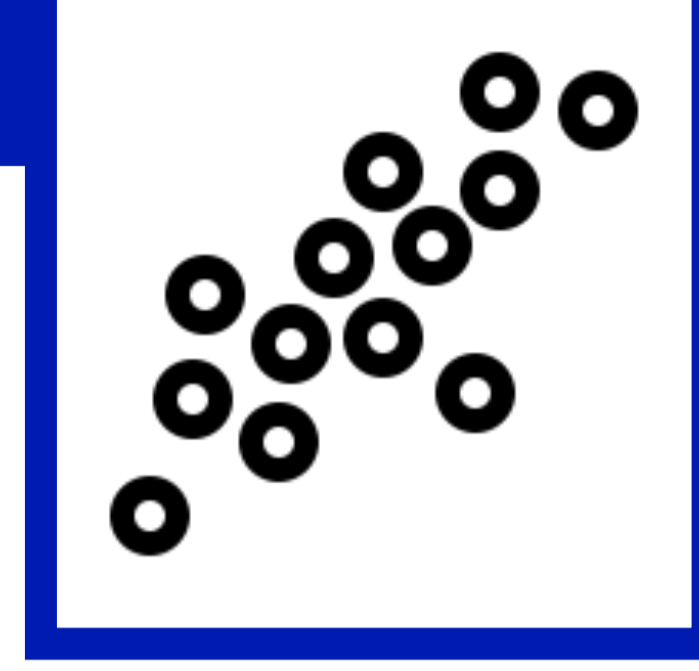
Electro-Magnetic Waves



Solar Wind



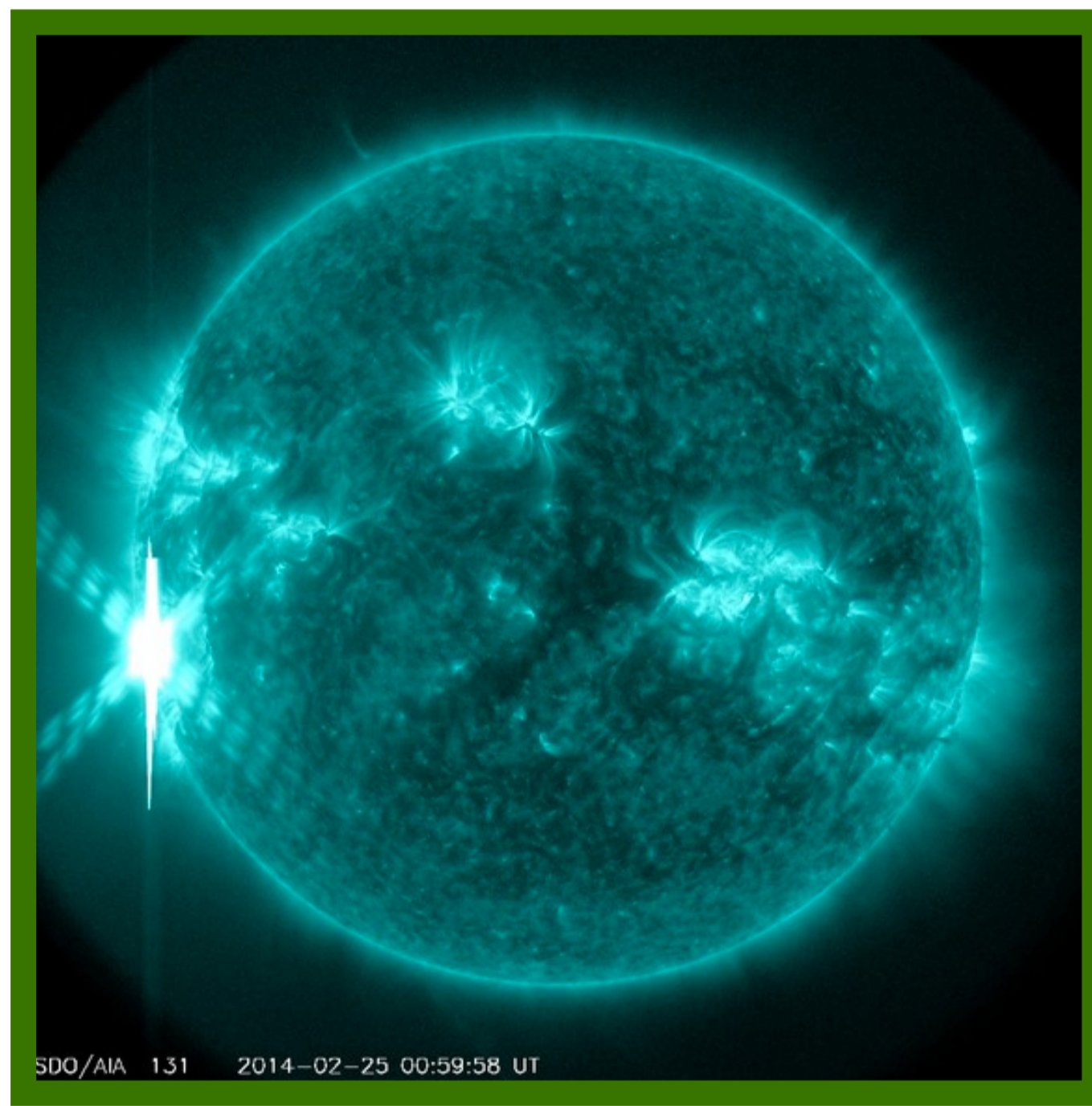
Solar Particles



Solar Storms

Flare

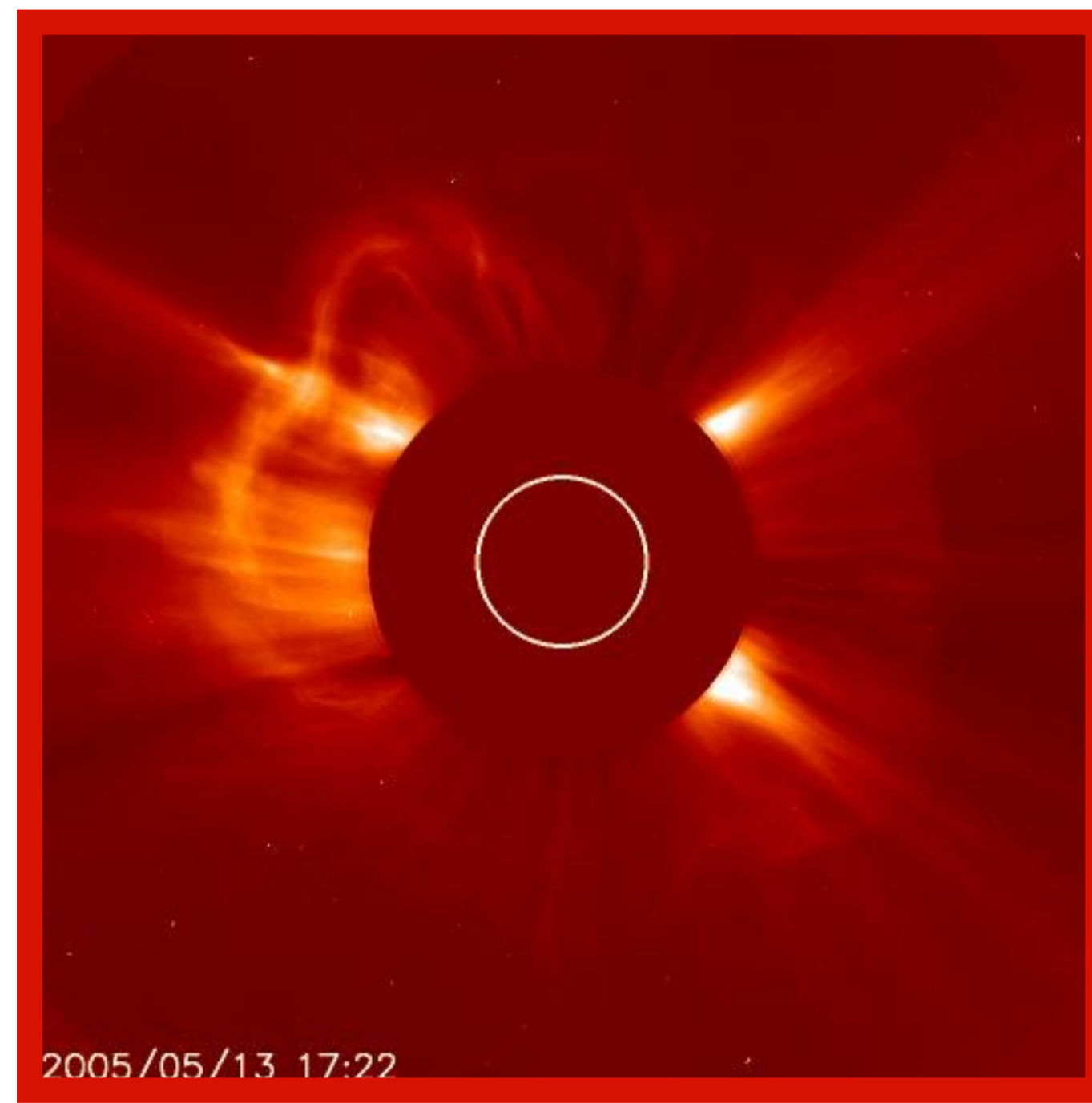
8 min



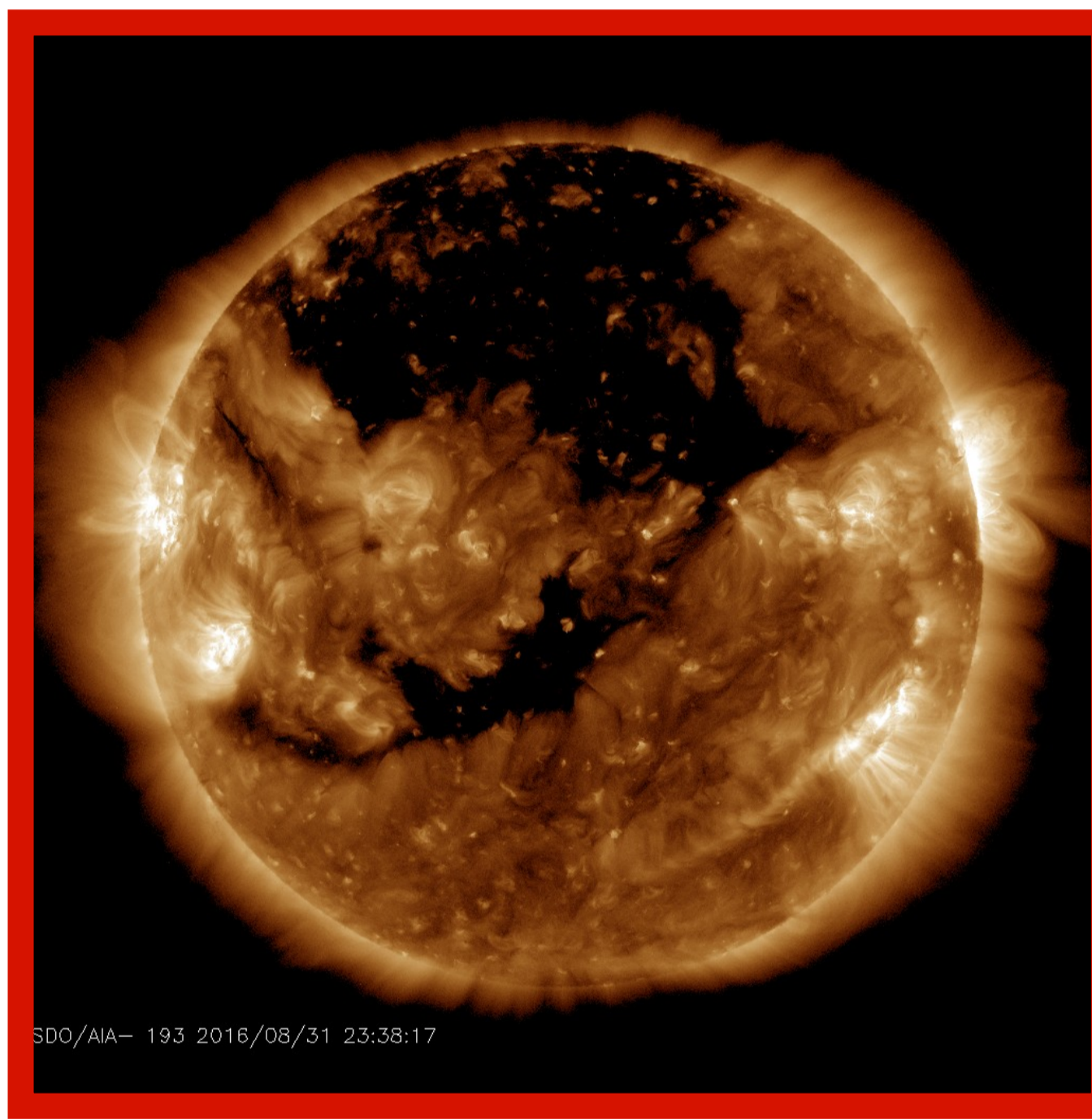
SDO/AIA

Coronal Mass Ejection
Coronal Hole

Days



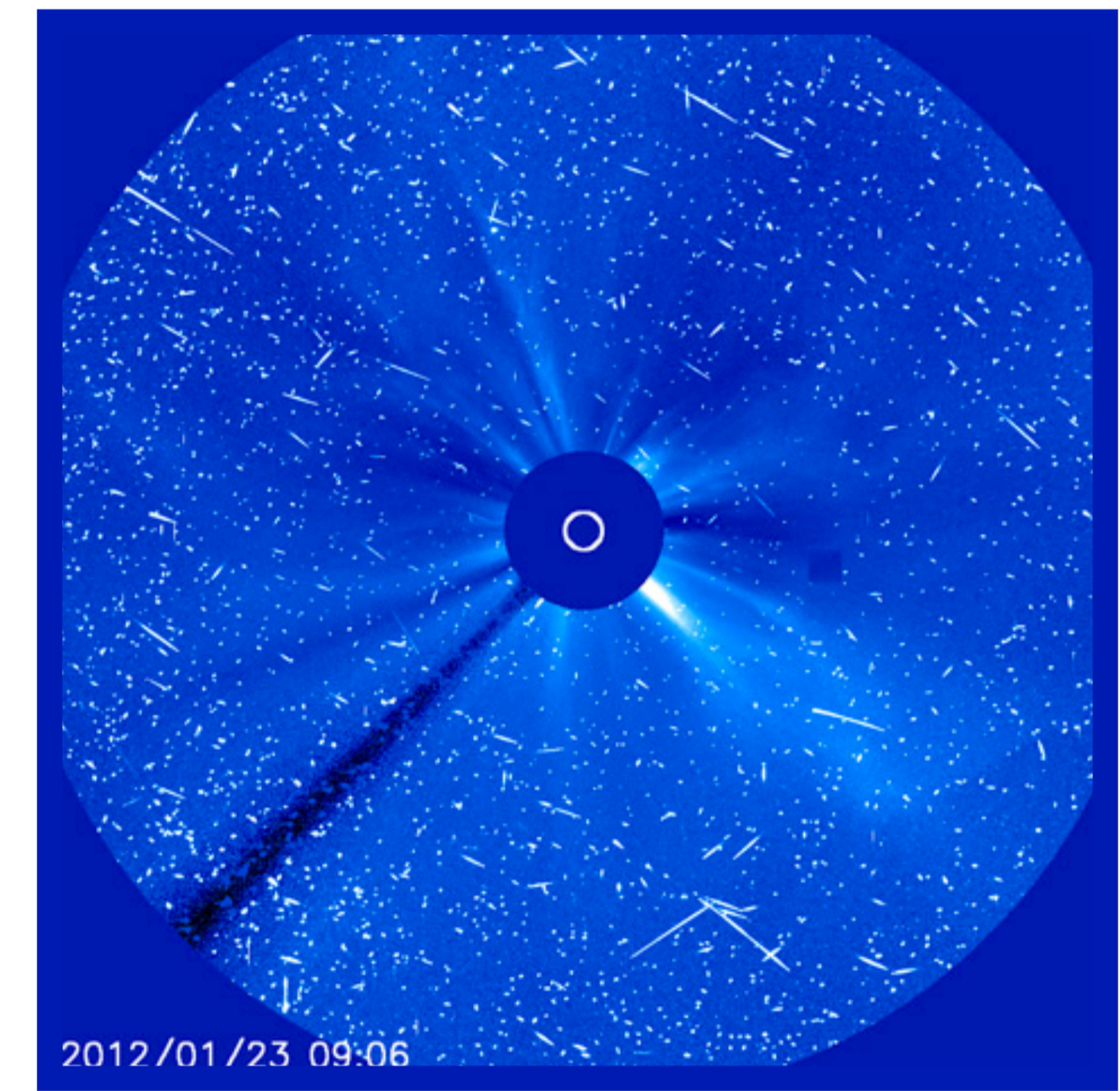
SOHO/LASCO



SDO/AIA

Particle Storm

Hours

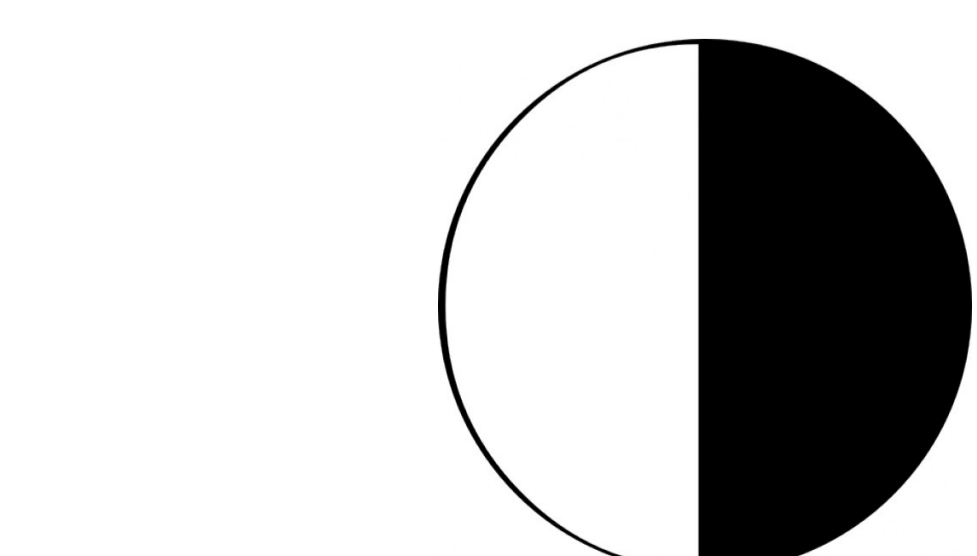


SOHO/LASCO



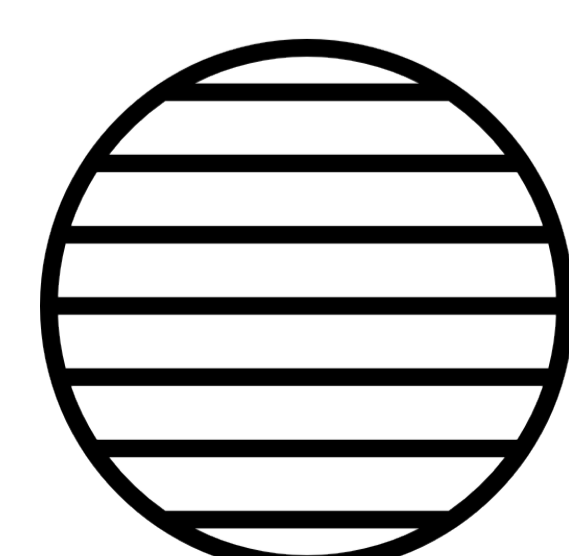
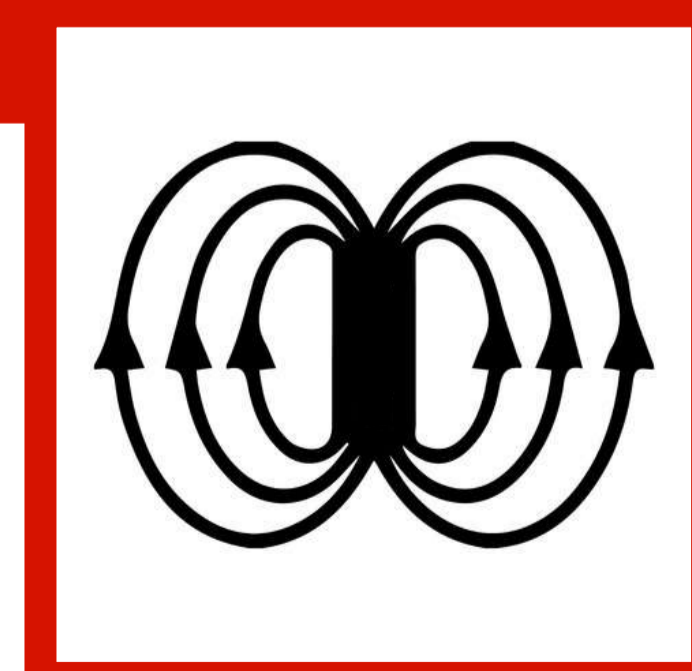
Space Weather

Radio Blackout



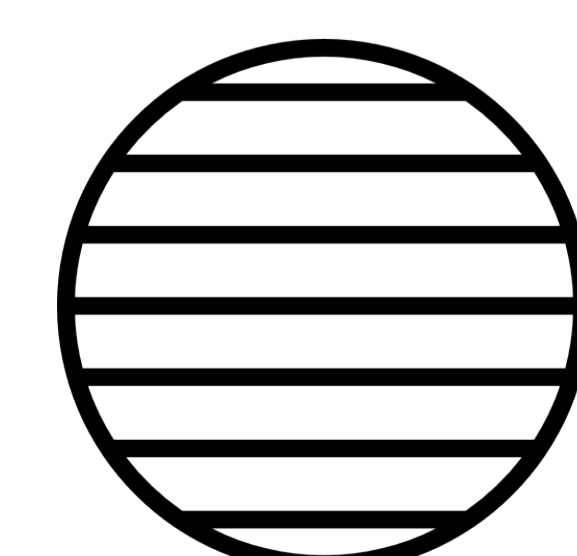
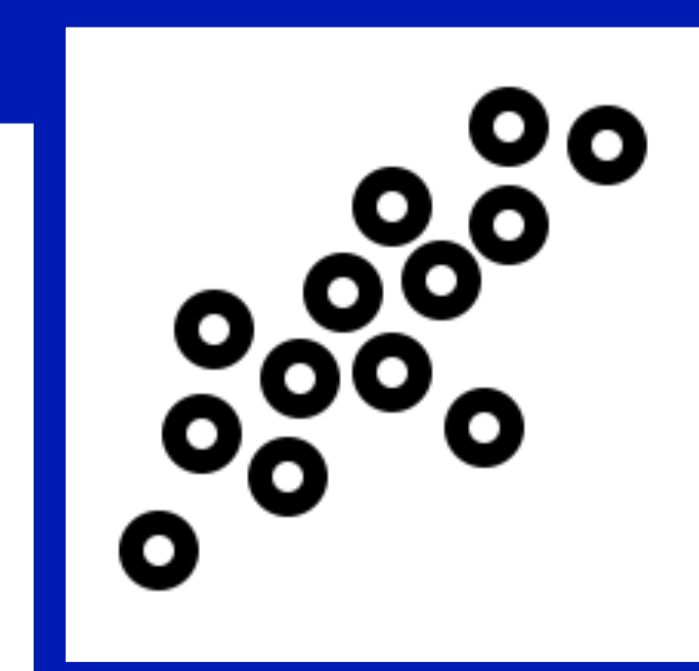
Illuminated Area

Geomagnetic Storm

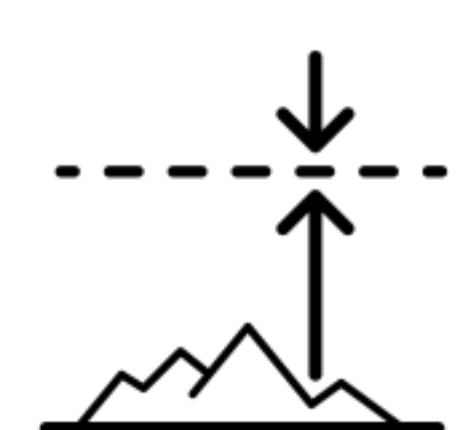


Latitude

Solar Radiation Storm

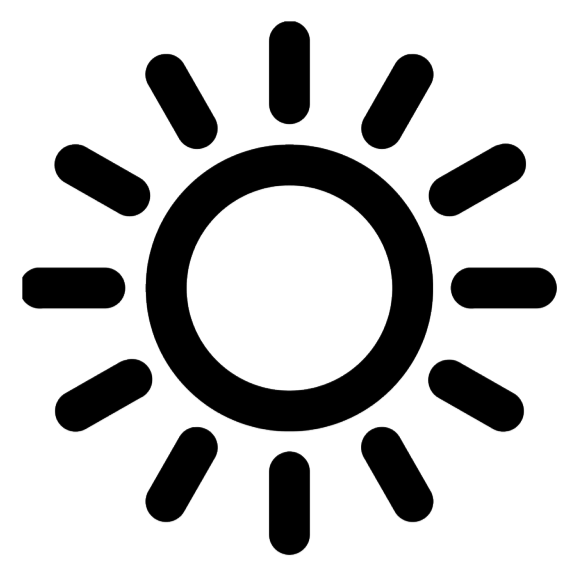


Latitude

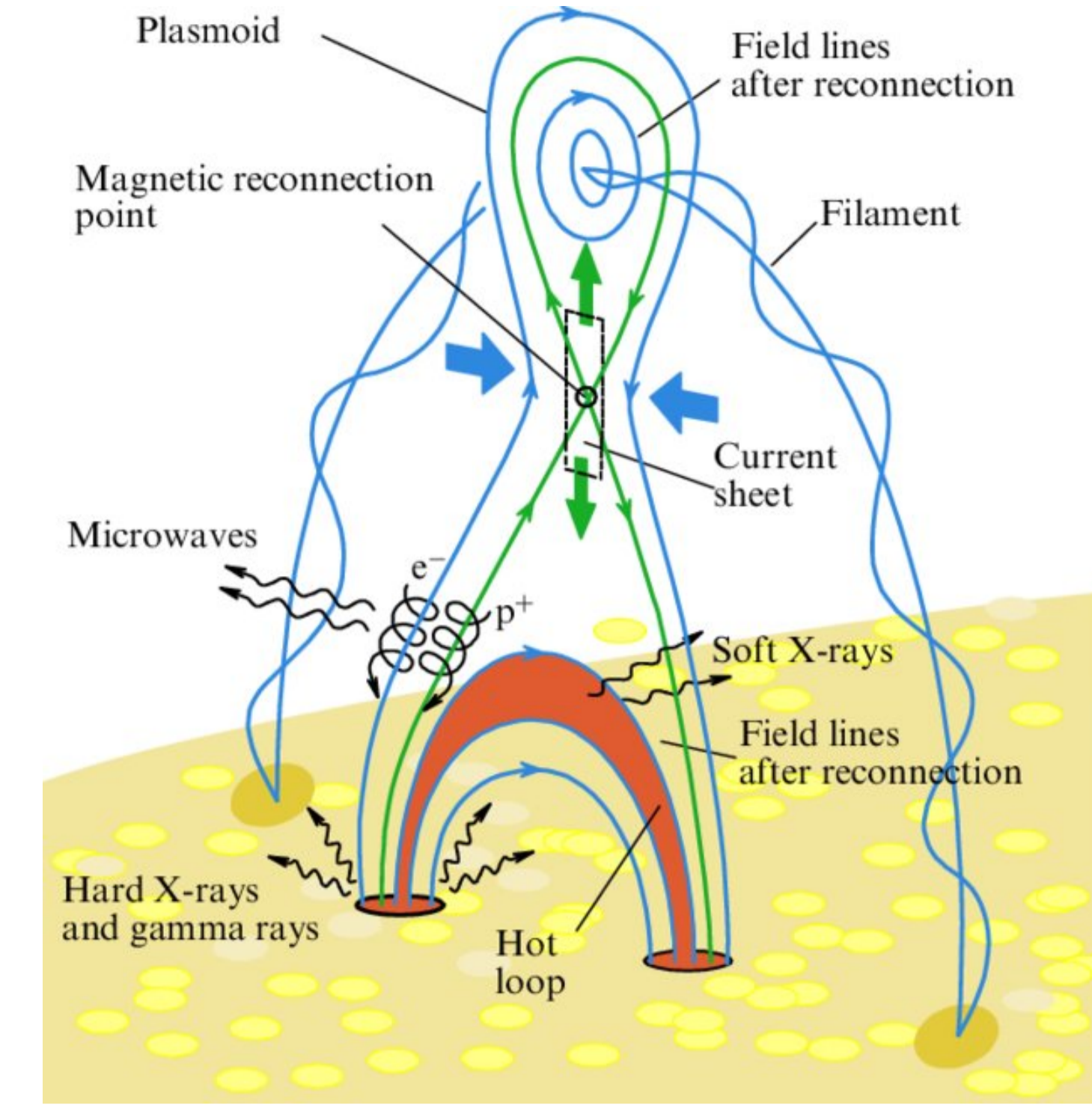
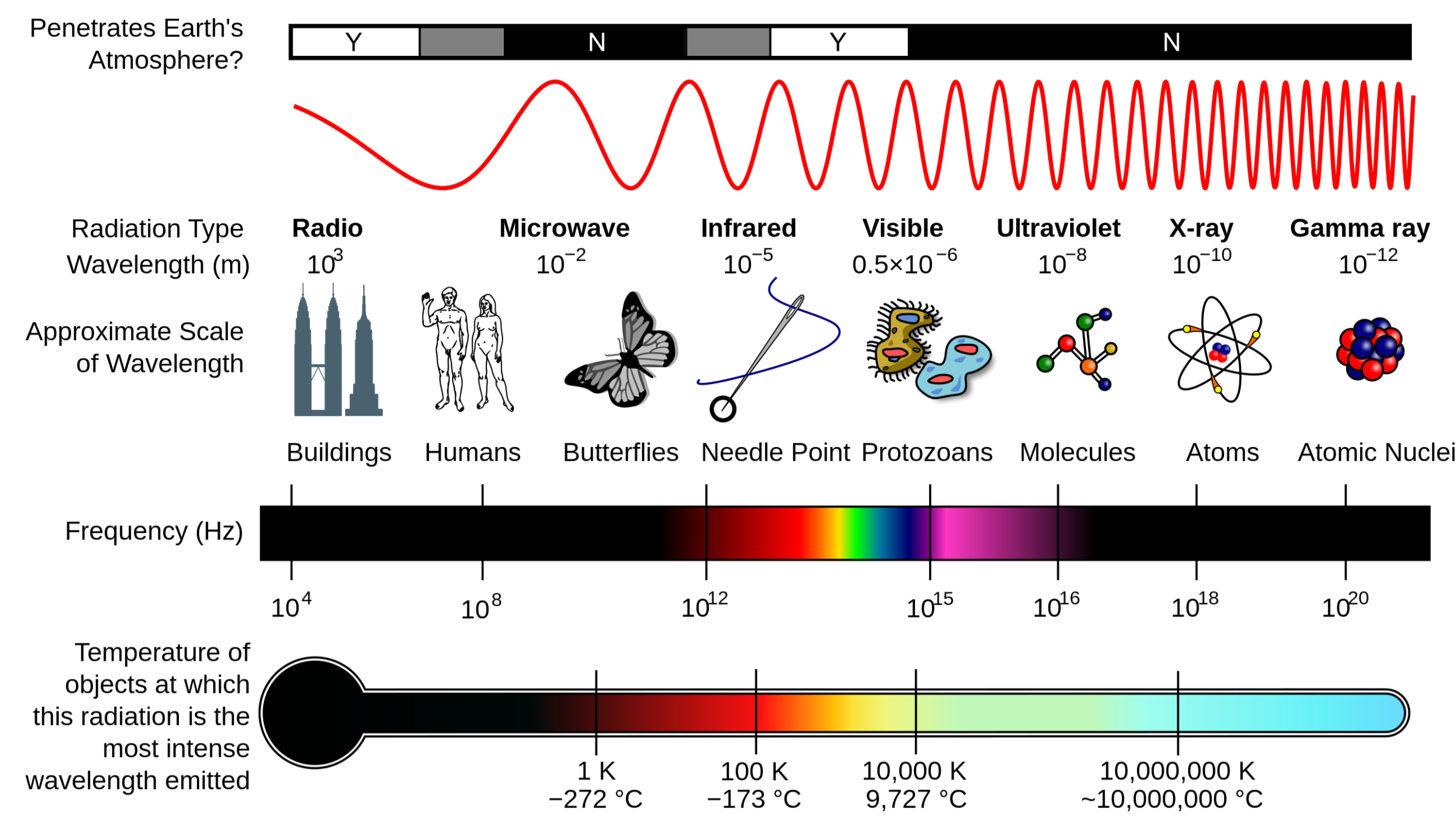


Altitude

Area of Impact



Electro-Magnetic Waves



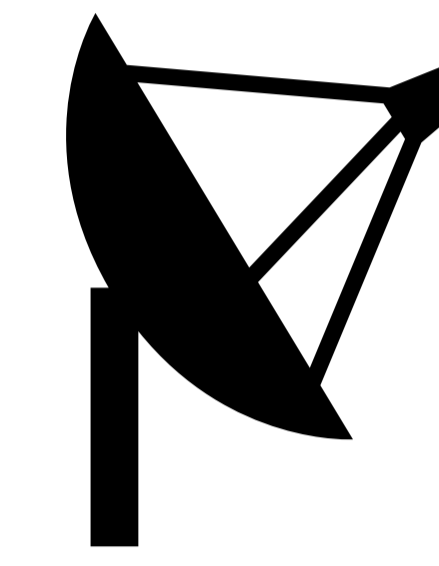
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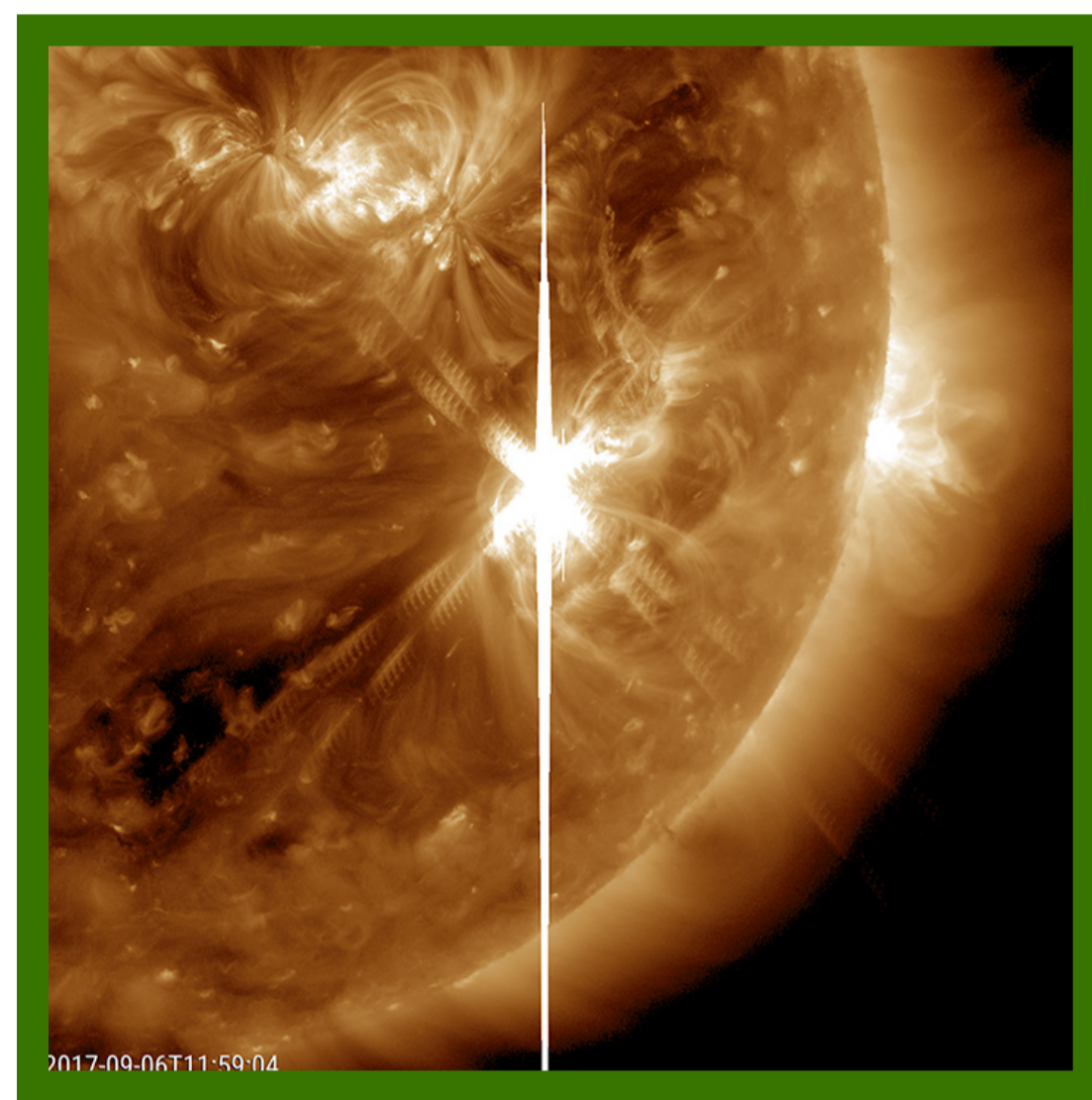
Flare

8 min

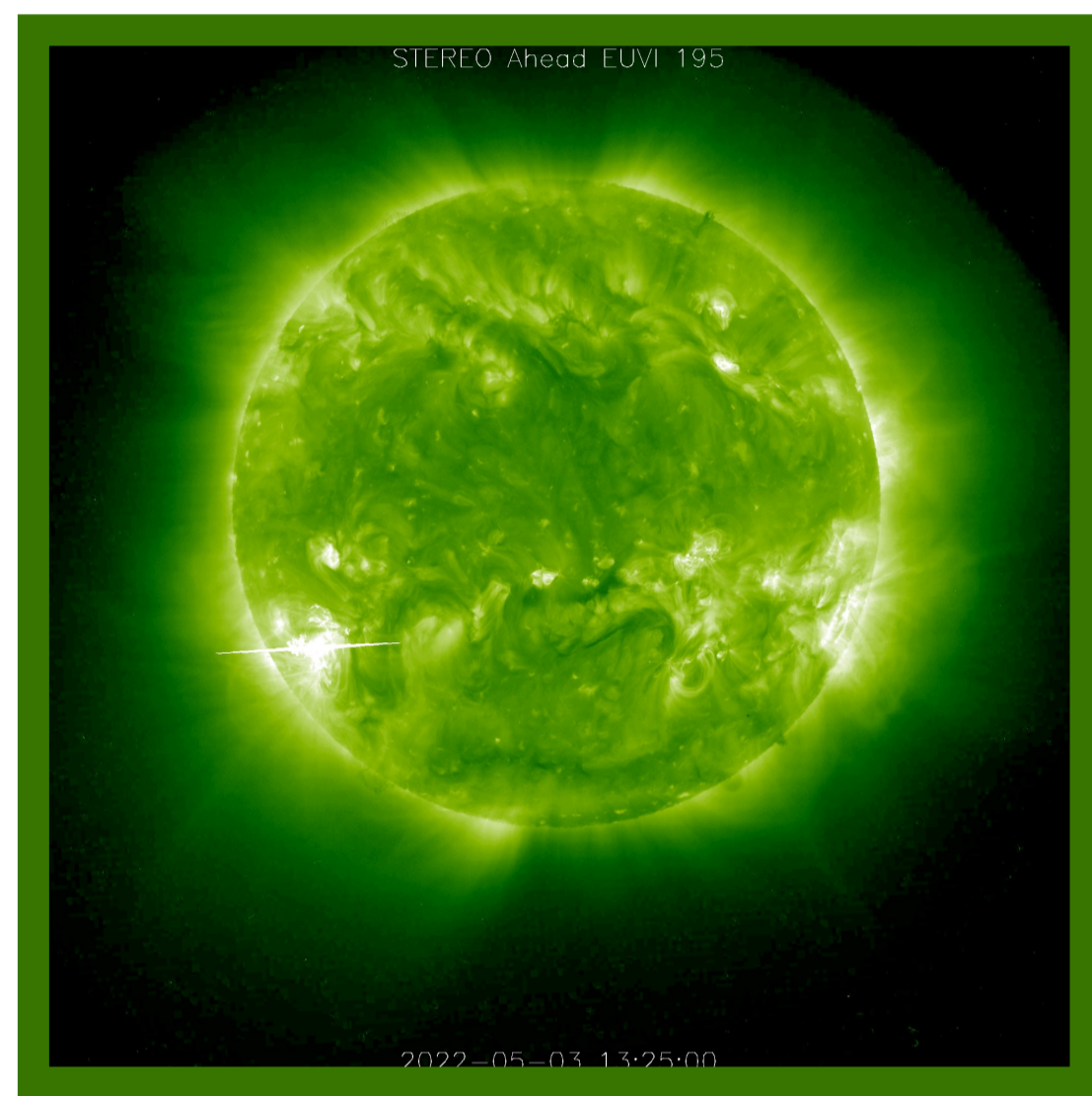
Solar Storms



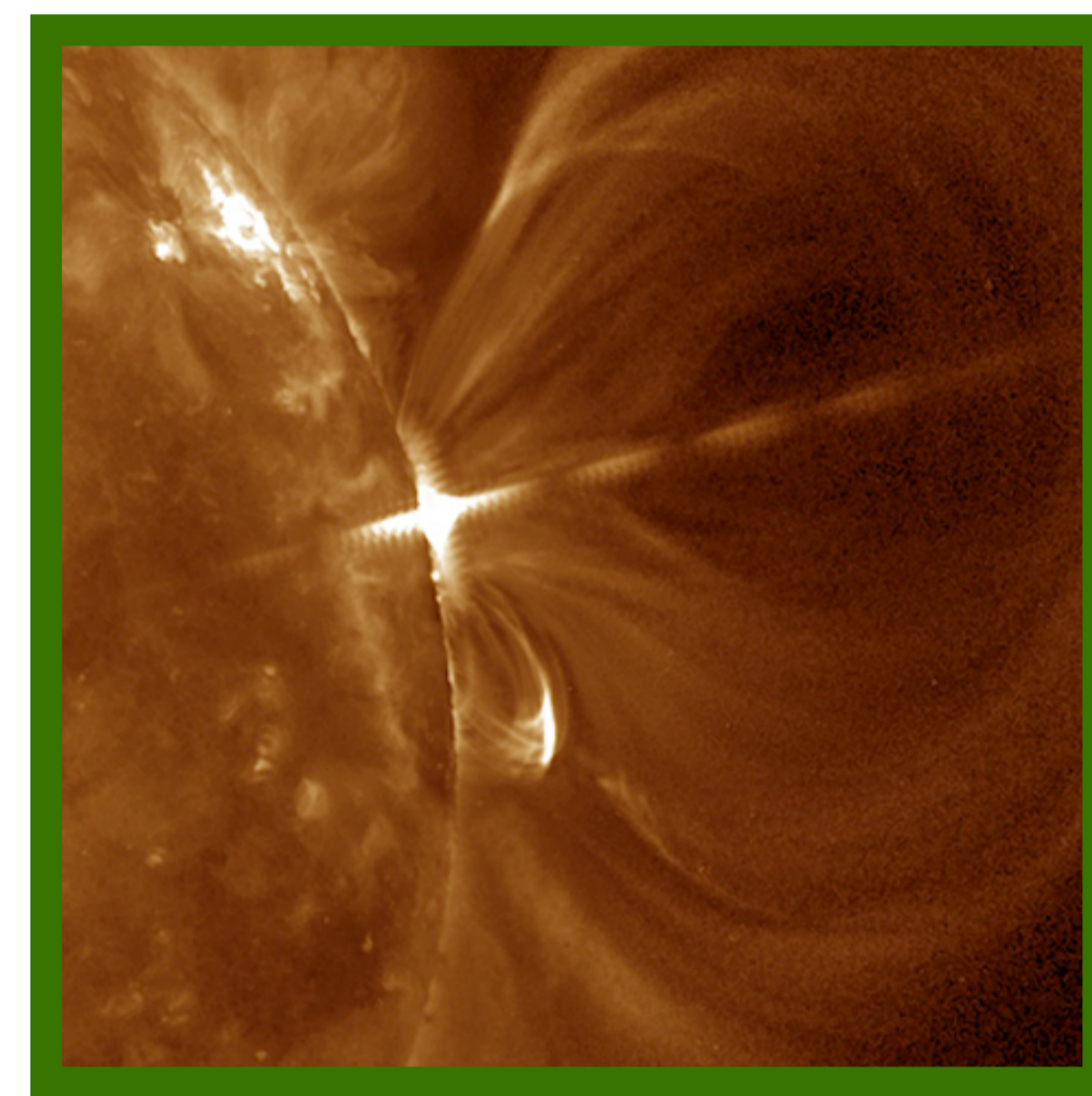
Solar Radio Burst



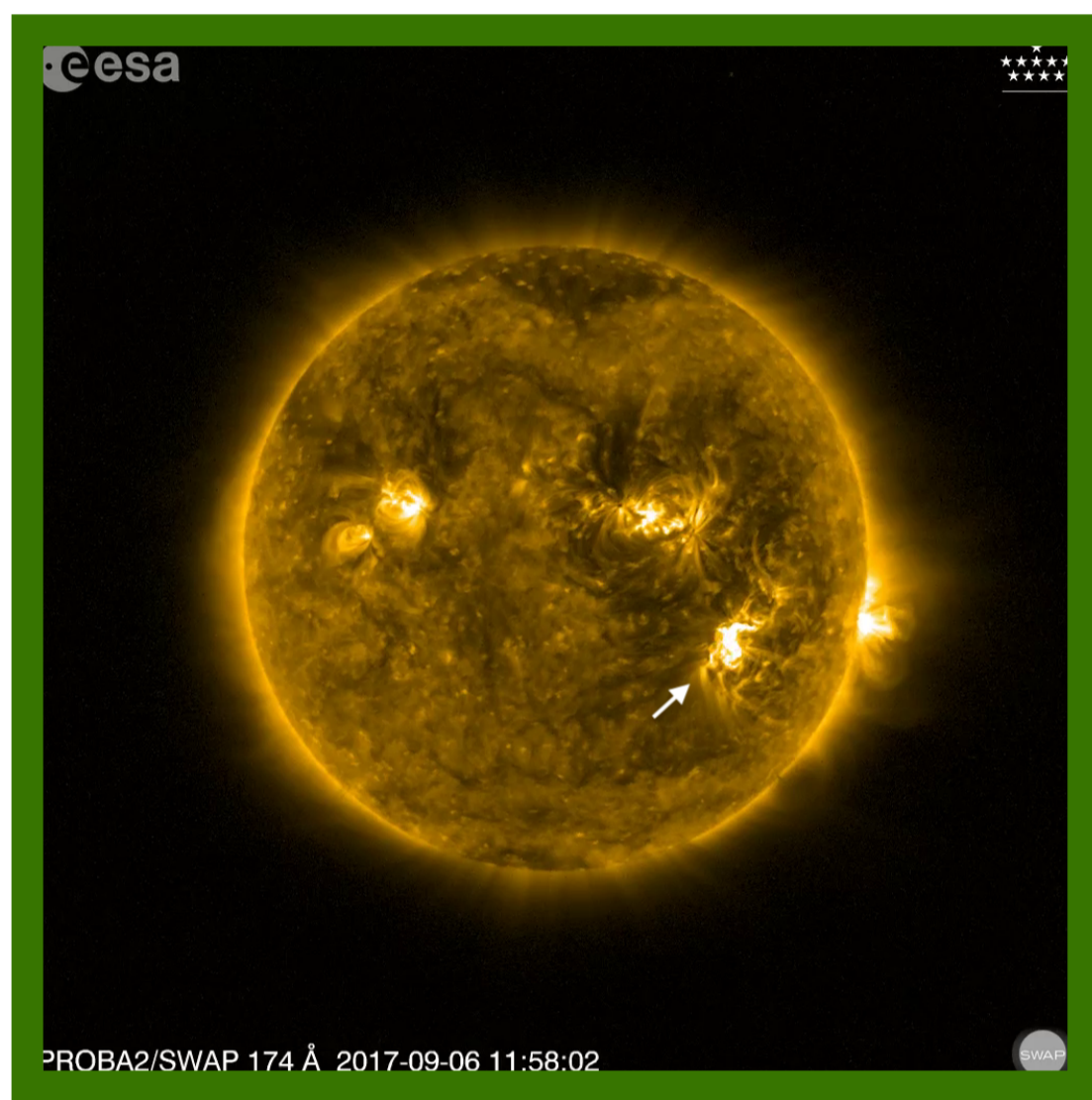
SDO/AIA



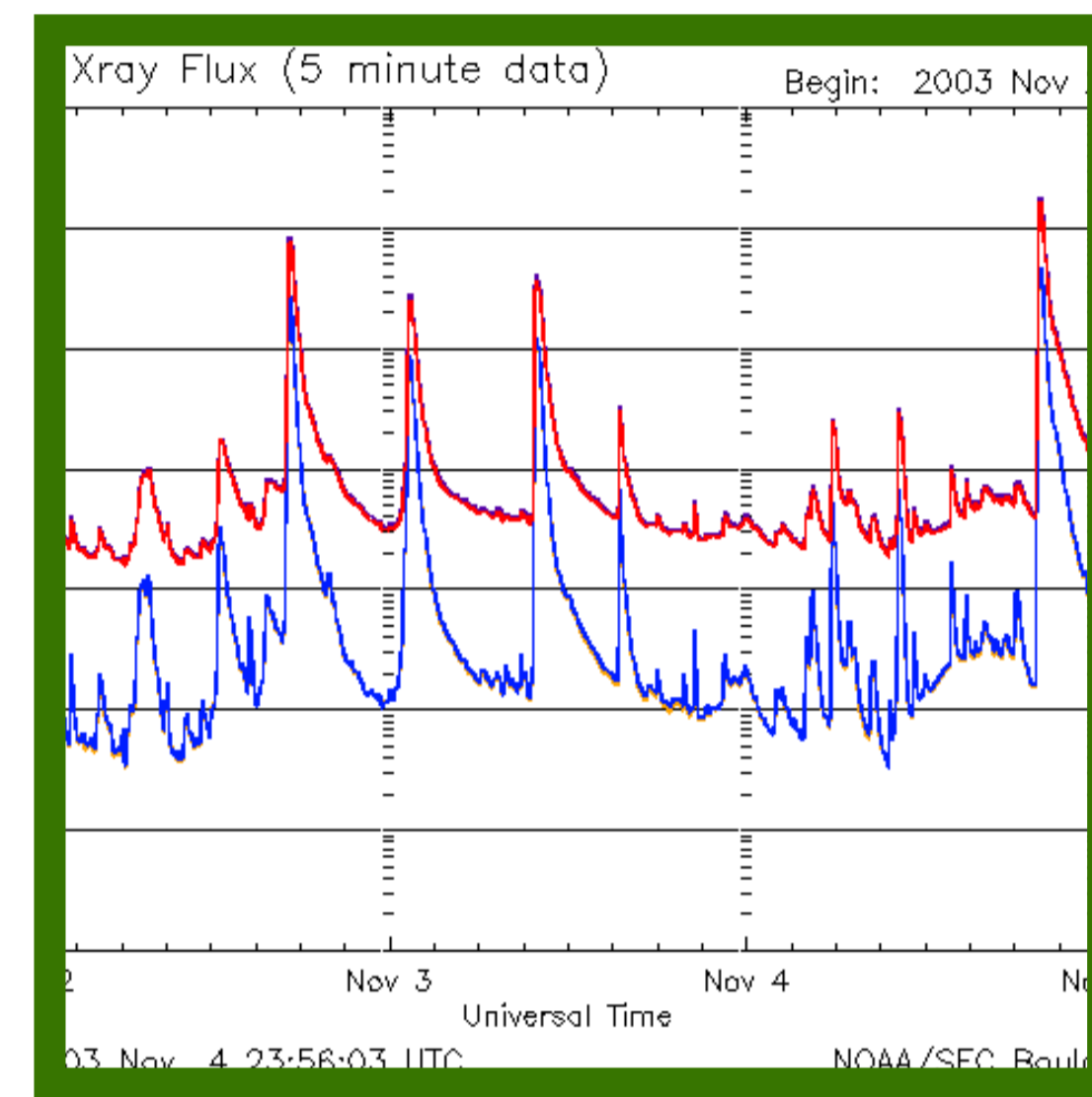
STEREO/EUVI



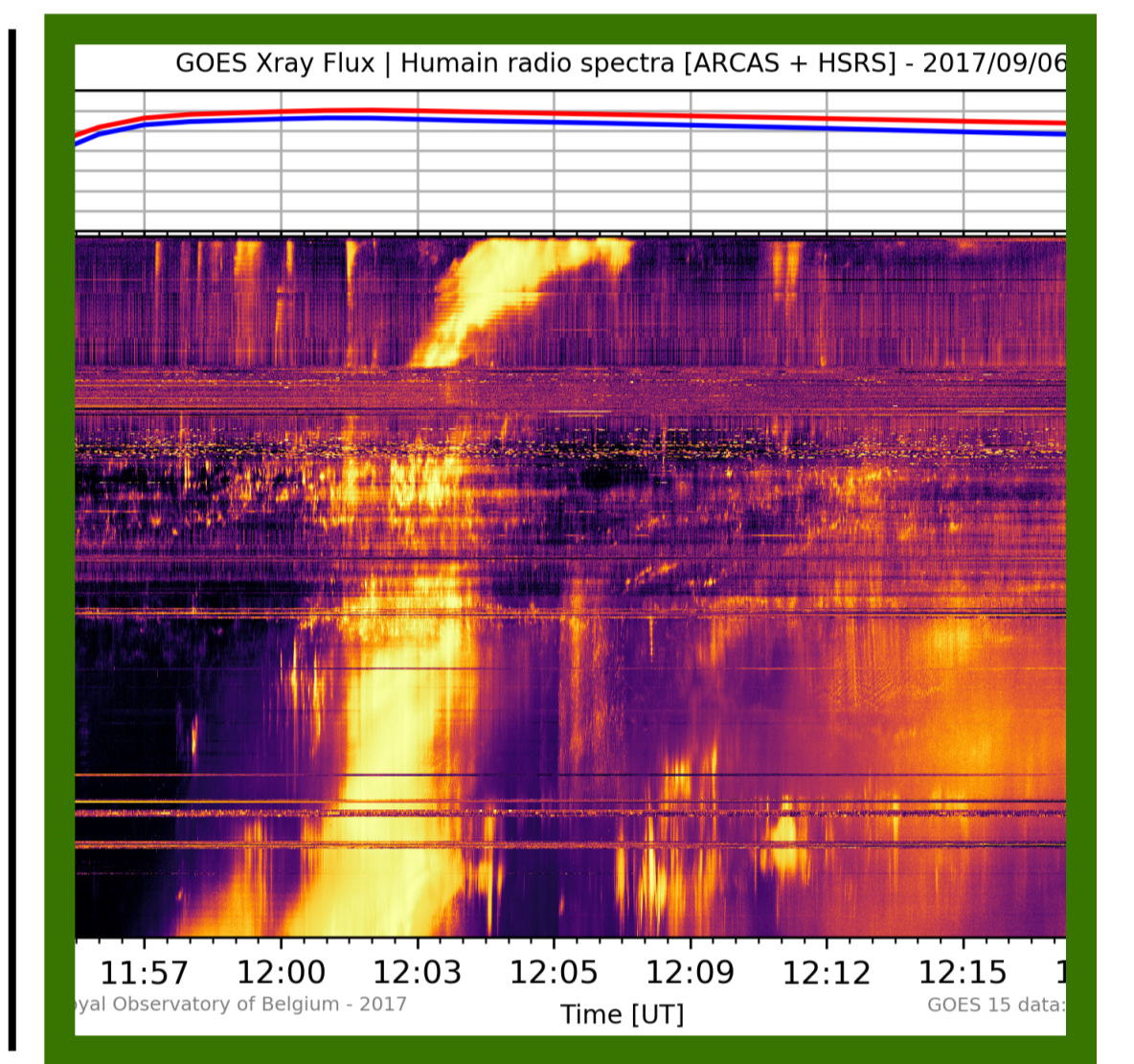
GOES/SUVI



PROBA2/SWAP



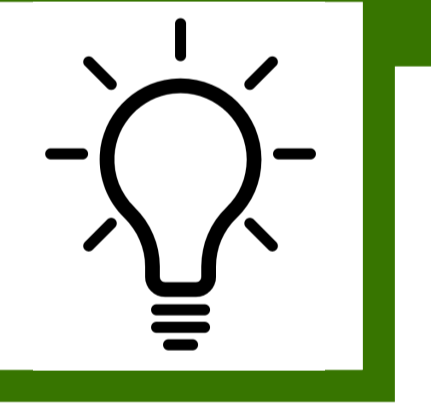
GOES



ROB/Humain

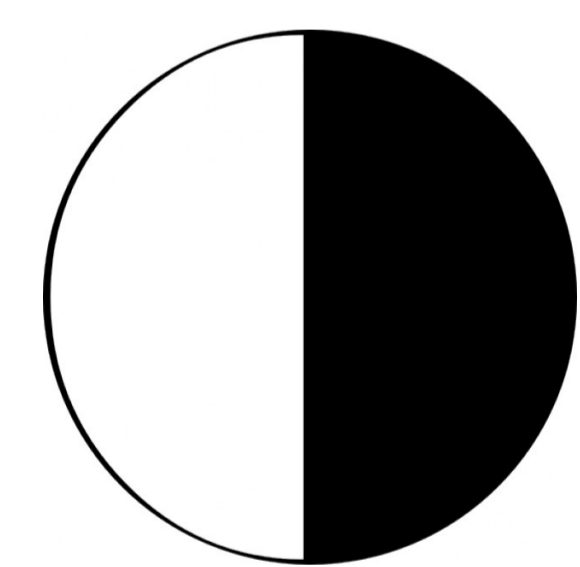


Radio Blackout



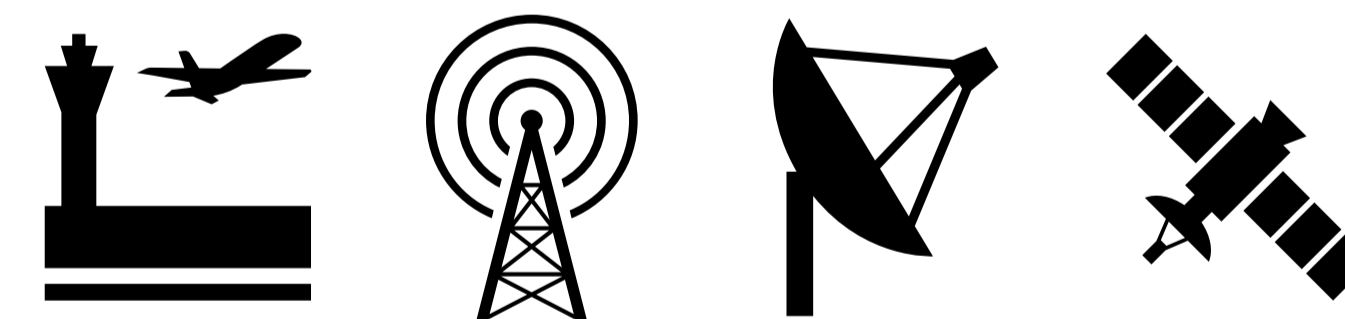
Space Weather

Area of Impact

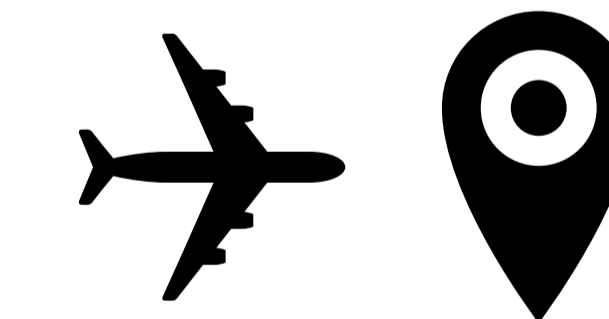


Illuminated Area

Effects

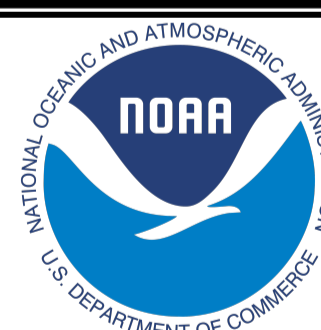


Radio Disturbance



Positioning Navigation

Radio Blackouts



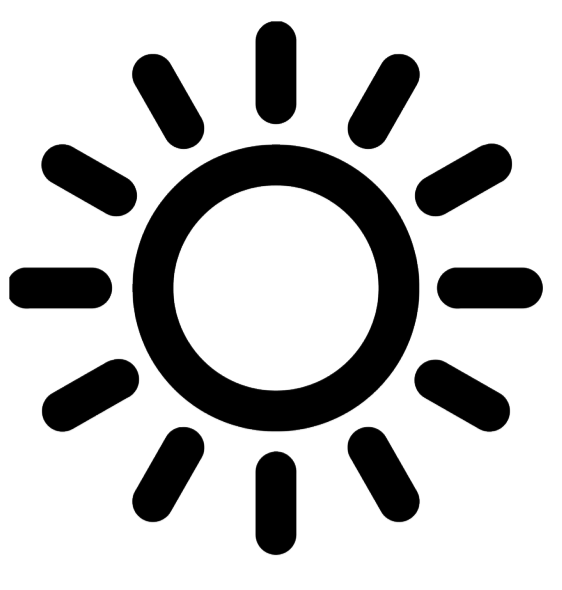
| | | | GOES X-ray peak brightness by class and by flux* | Number of events when flux level was met; (number of storm days) |
|------------|----------|---|--|--|
| R 5 | Extreme | HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. 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 of the Earth, 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 of the Earth, 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 $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

** Other frequencies may also be affected by these conditions.

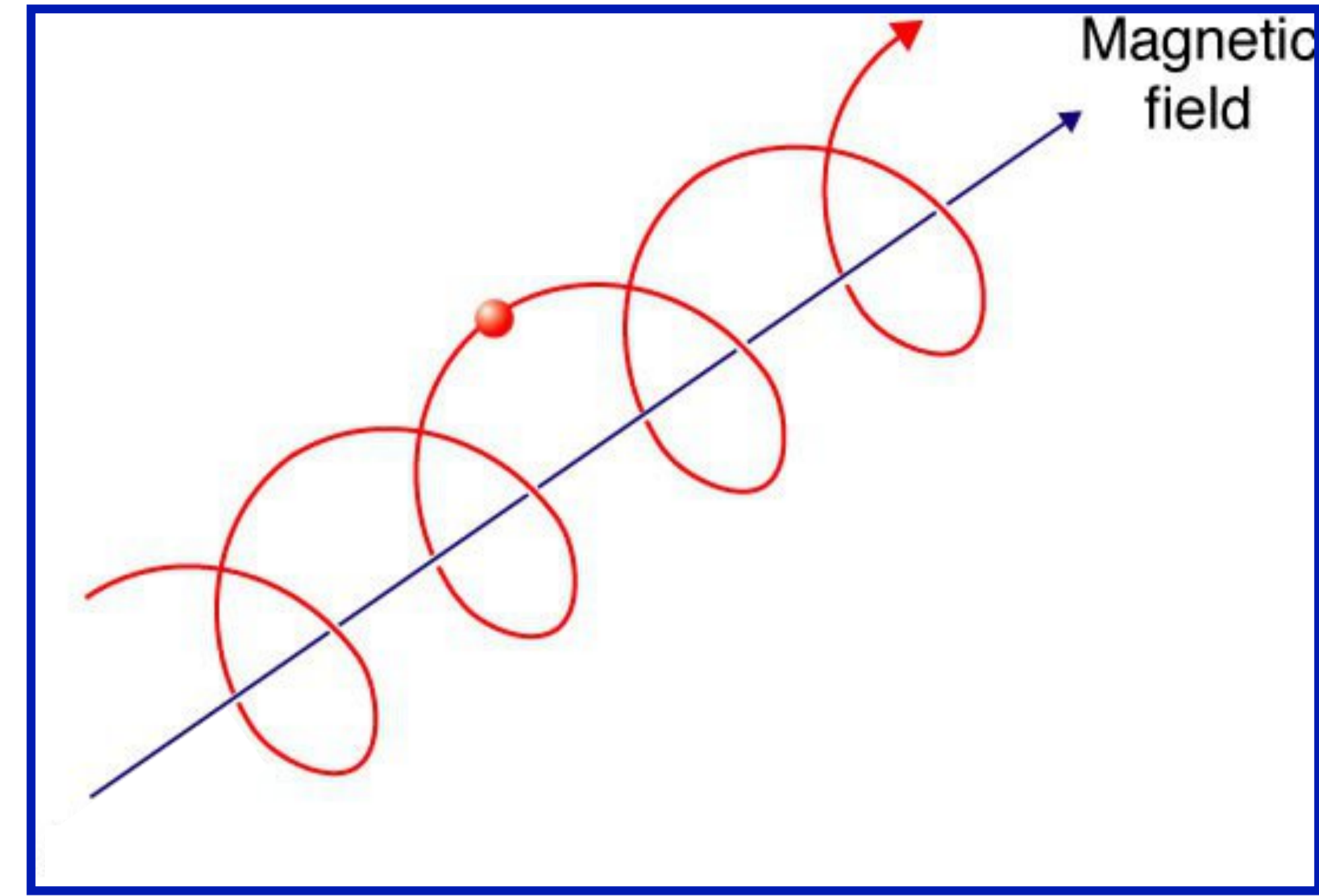
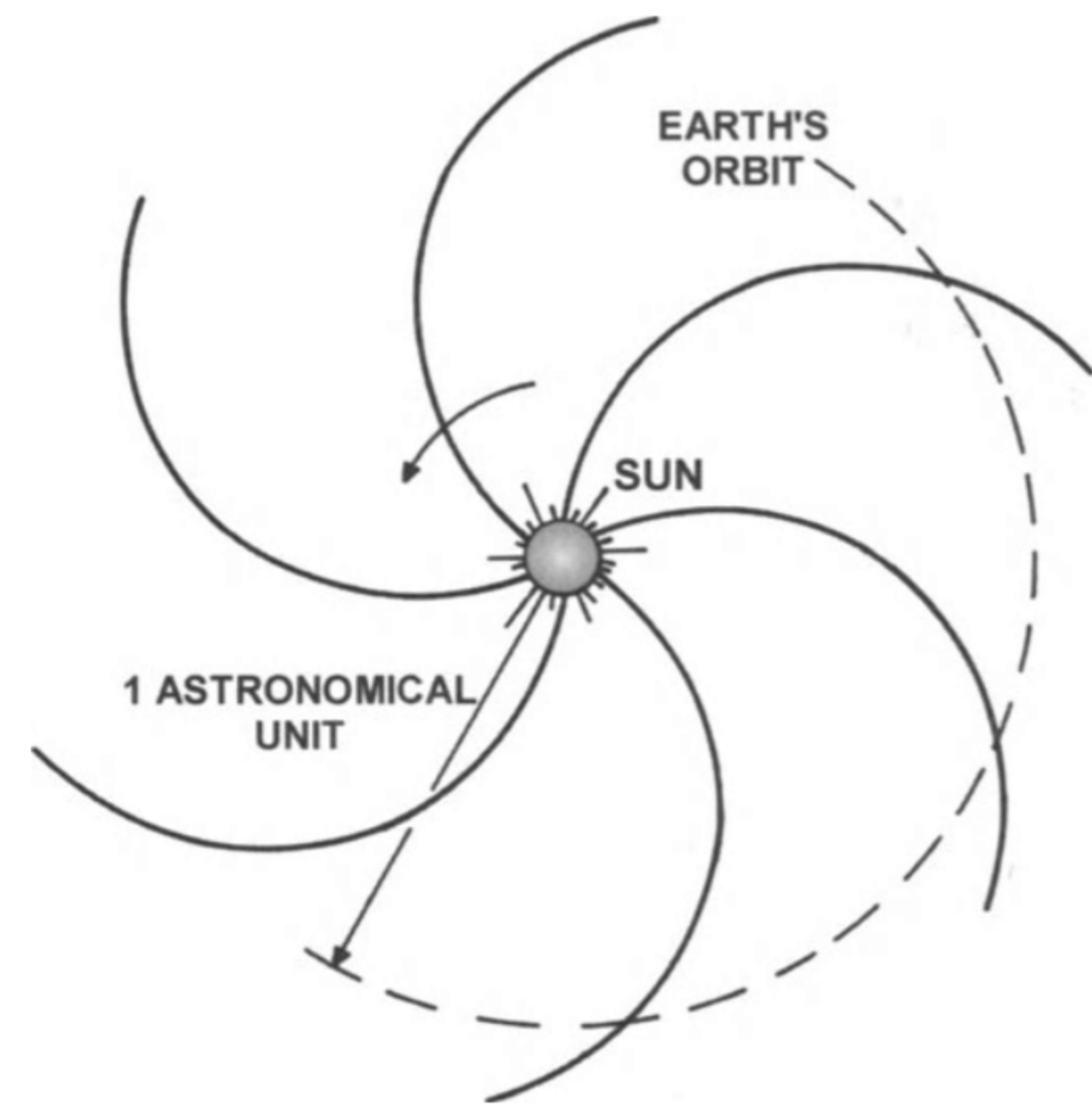
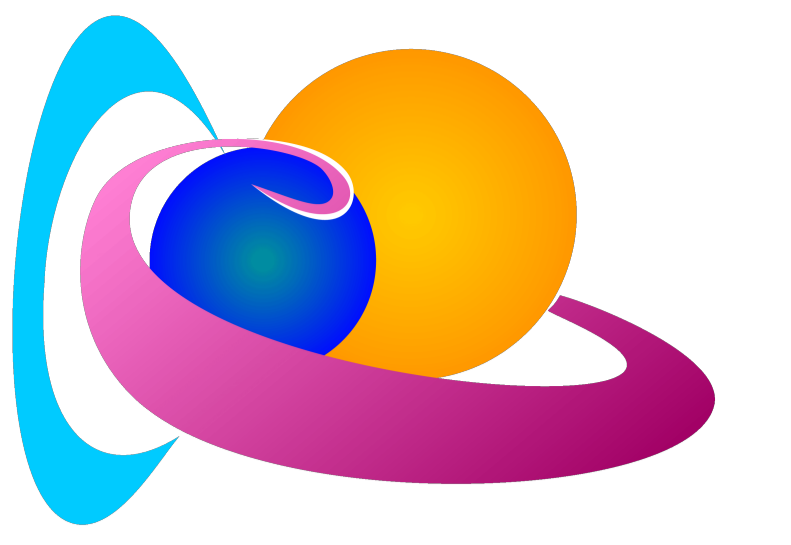
URL: www.swpc.noaa.gov/NOAA_scales

April 7, 2011



Solar Particles

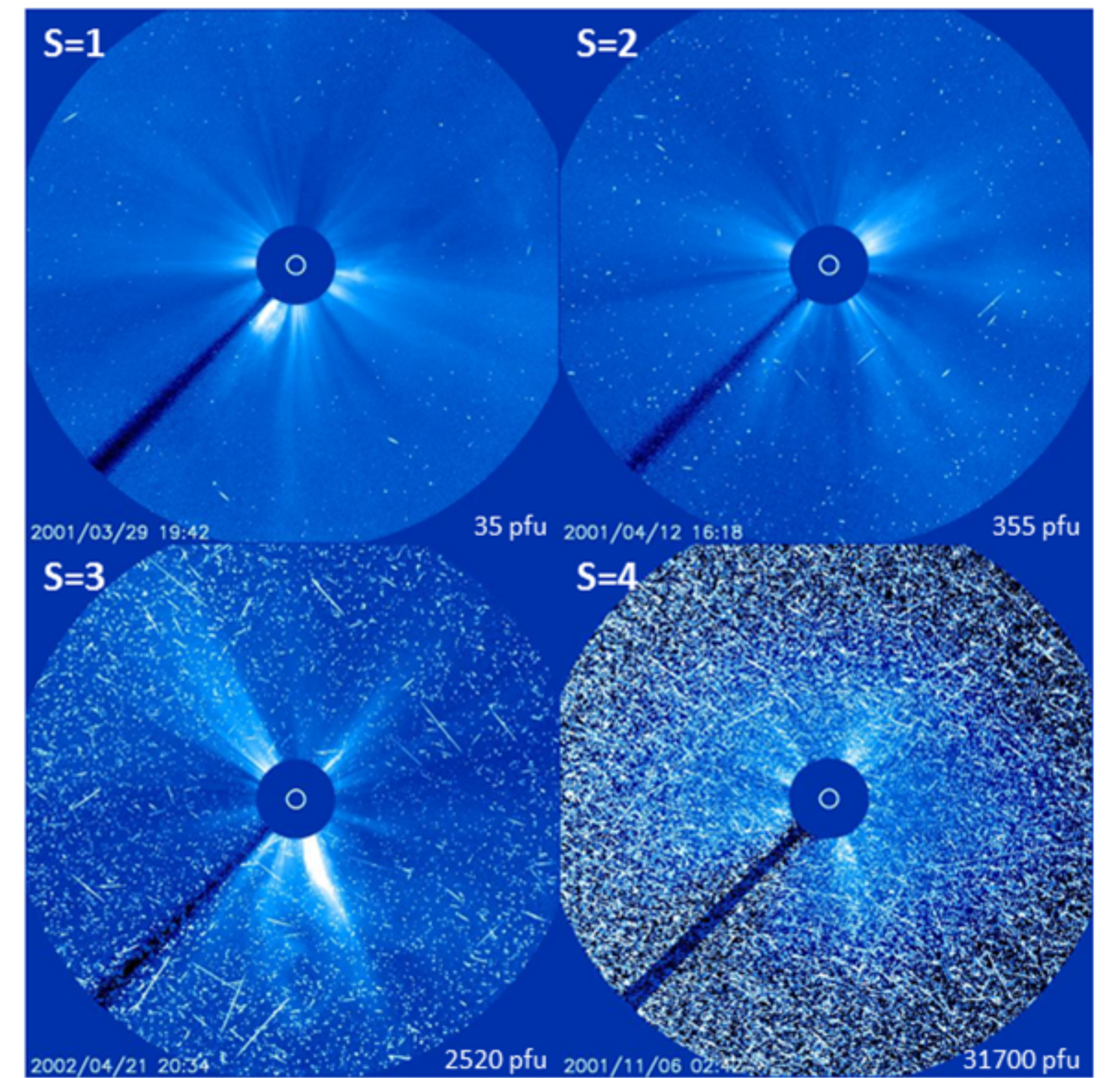
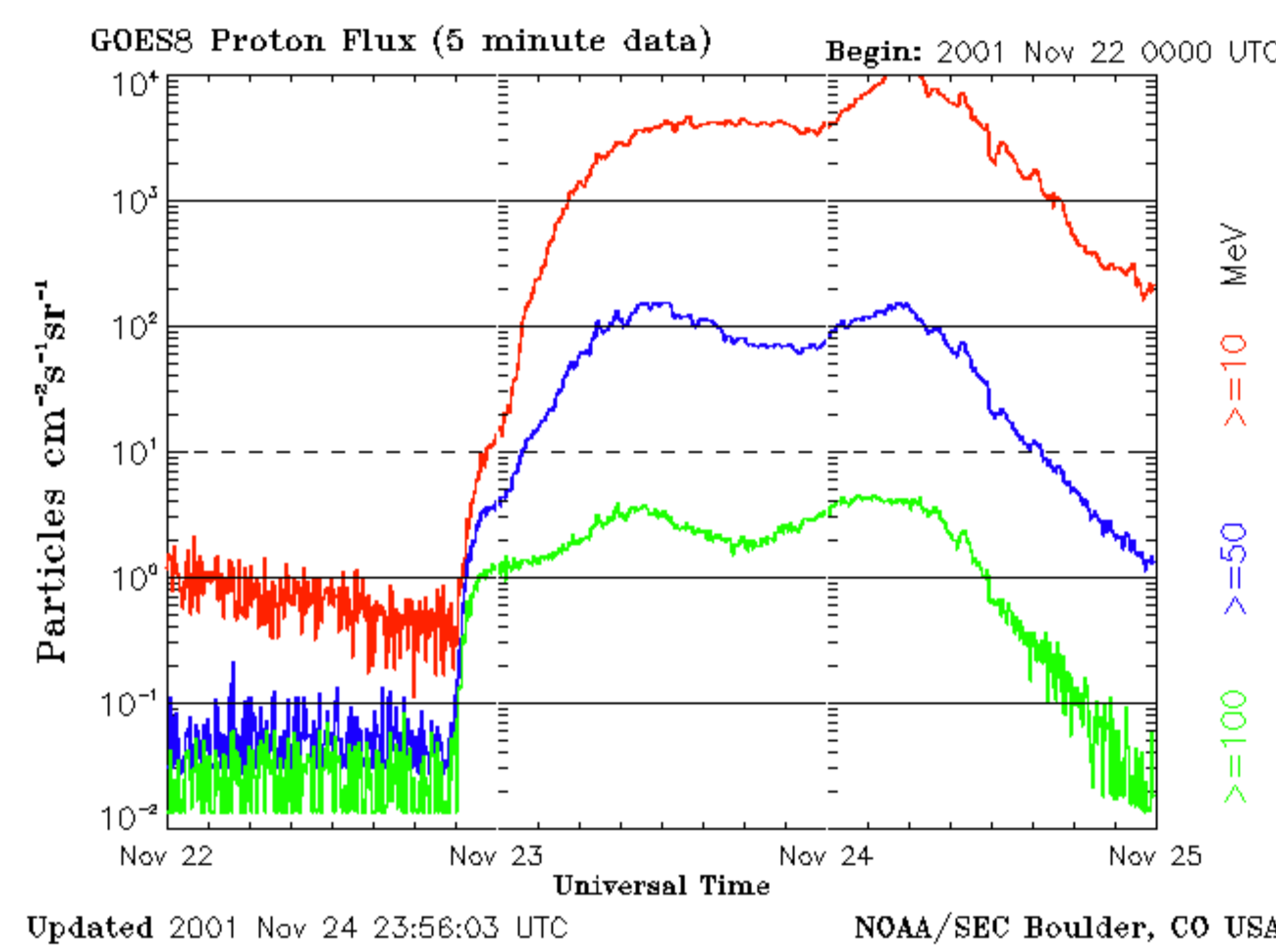
Solar Energy



Particle Storm

Hours

Solar Storms



GOES

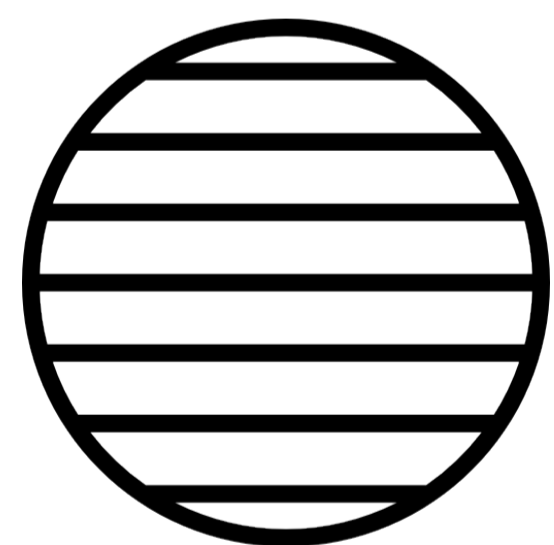
SOHO/LASCO



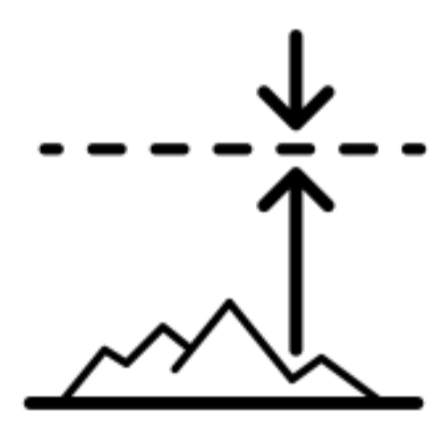
Solar Radiation Storm

Space Weather

Area of Impact

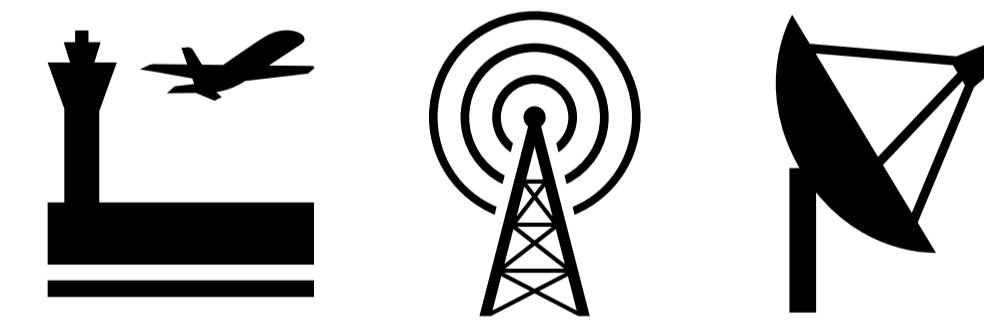


Latitude

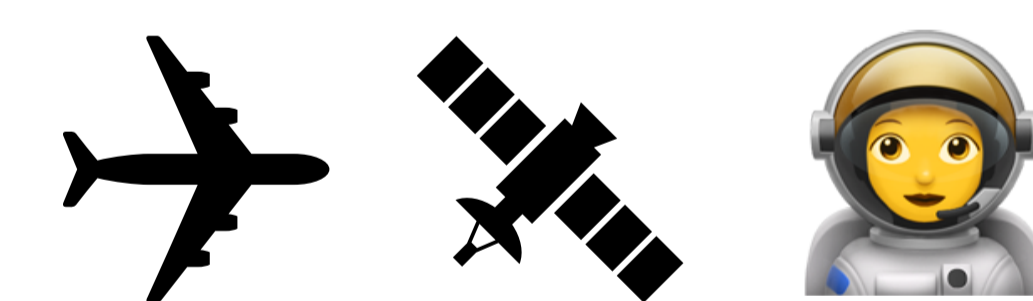


Altitude

Effects



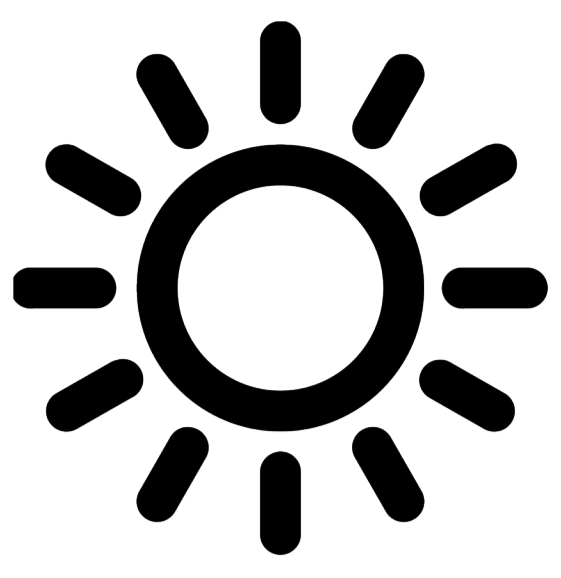
Radio Disturbance



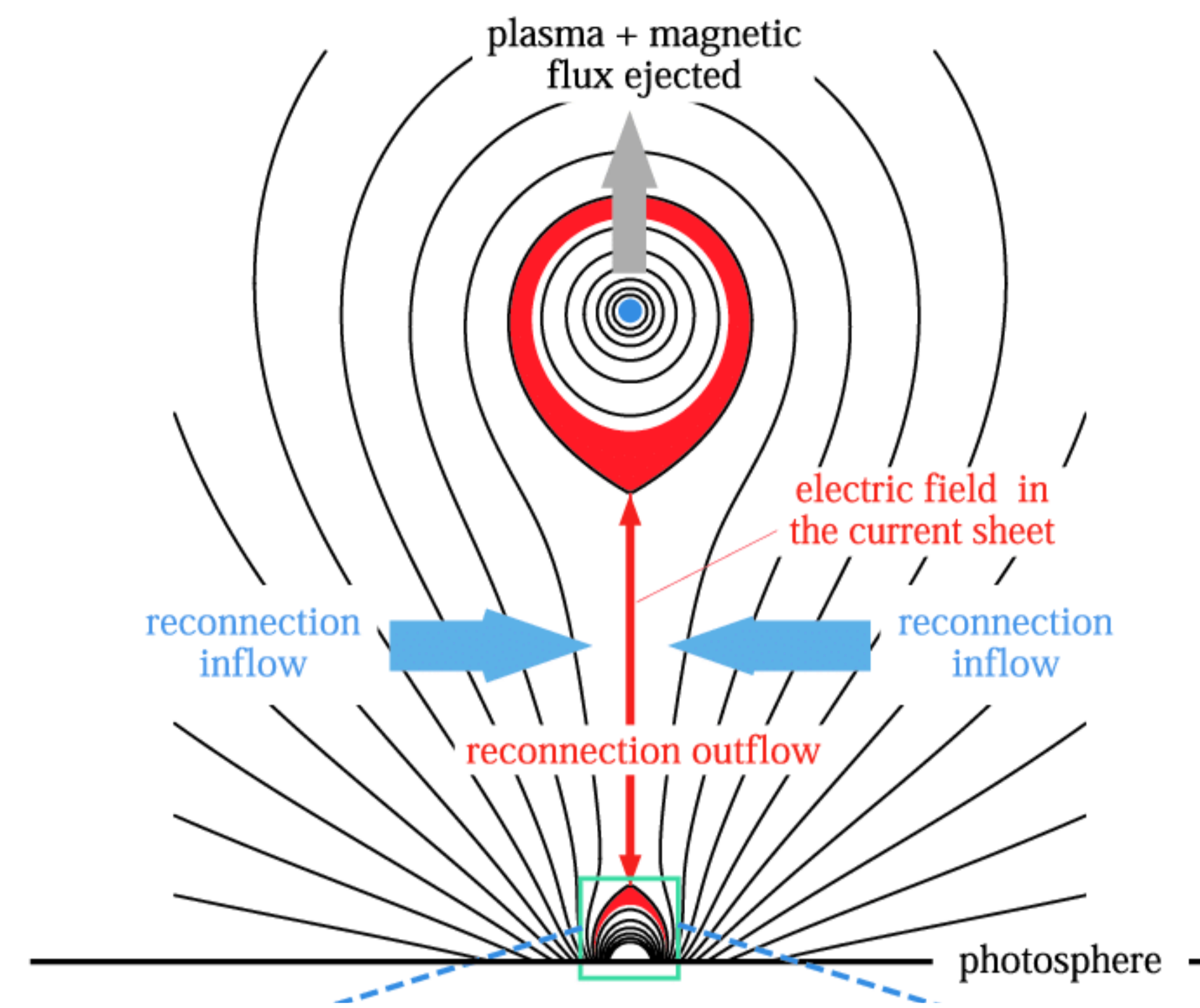
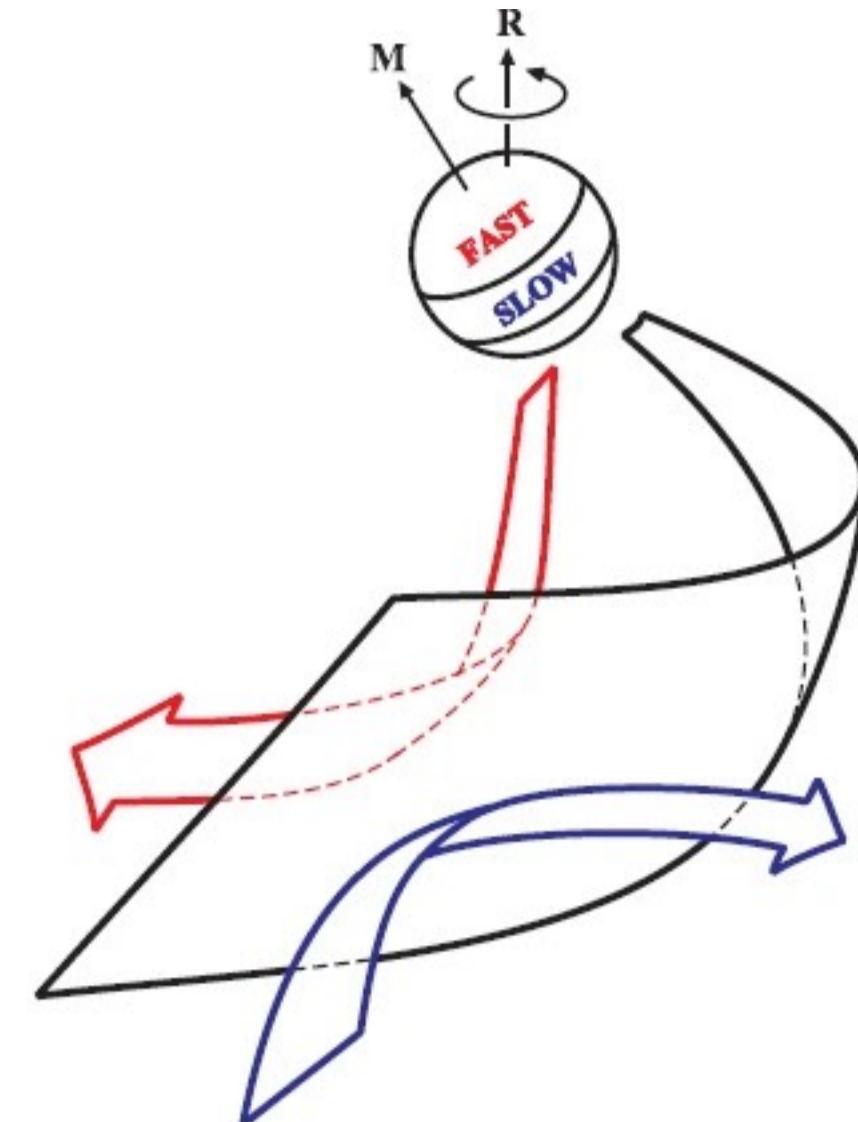
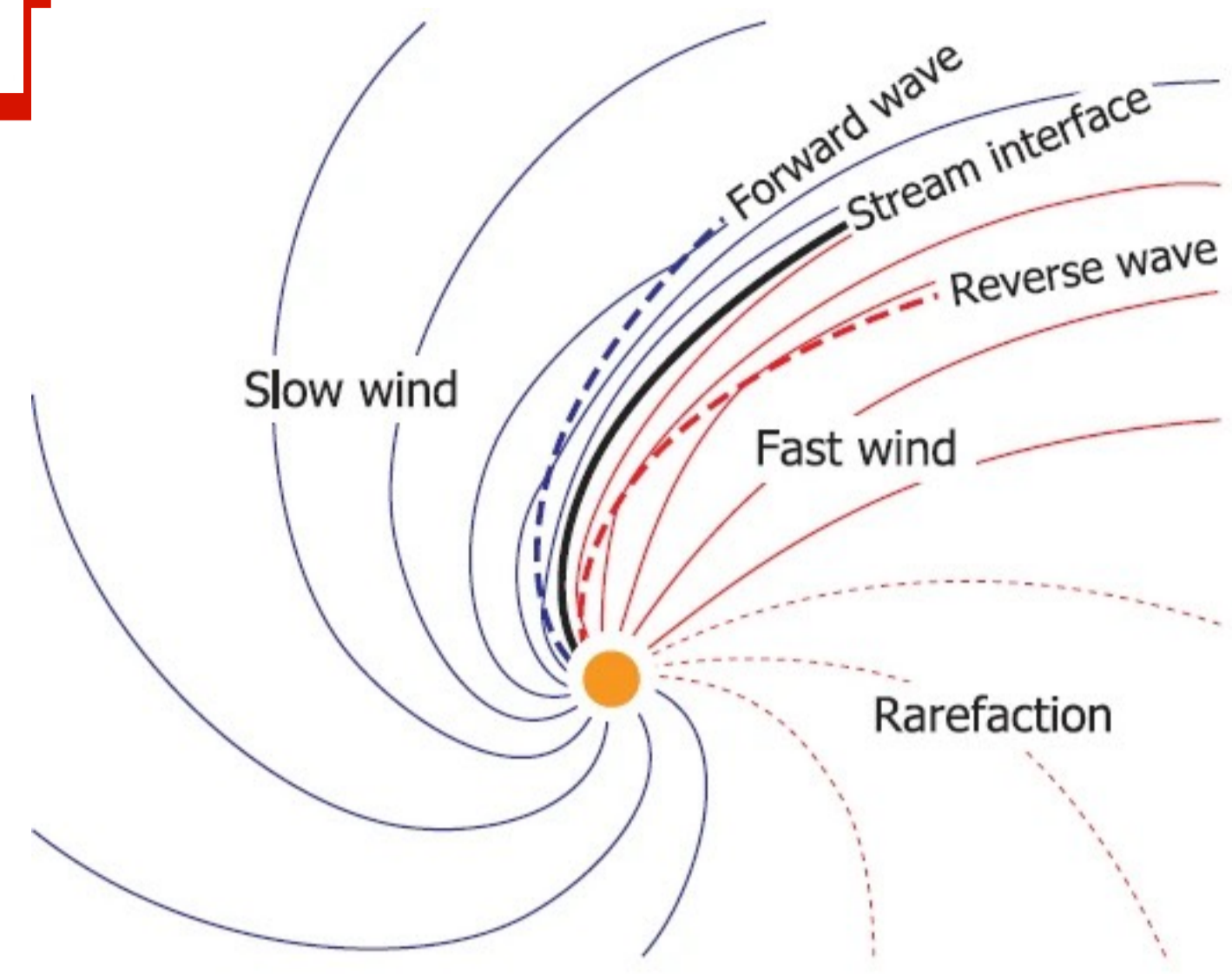
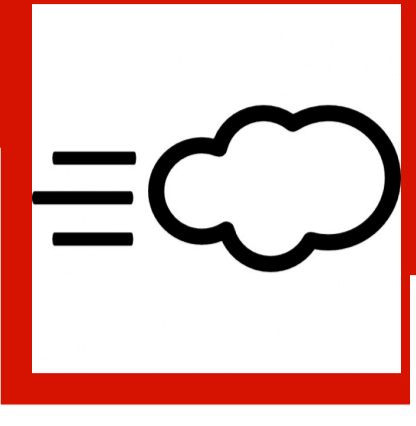
Radiation

| Solar Radiation Storms | | | Flux level of ≥ 10 MeV particles (ions)* | Number of events when flux level was met** |
|------------------------|----------|---|---|--|
| S 5 | Extreme | Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** 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; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk *** 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 high-flying aircraft at high latitudes may be exposed to radiation risk.*** 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: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected. | 10^2 | 25 per cycle |
| S1 | 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 $\text{s}^{-1}\text{ster}^{-1}\text{cm}^{-2}$ Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

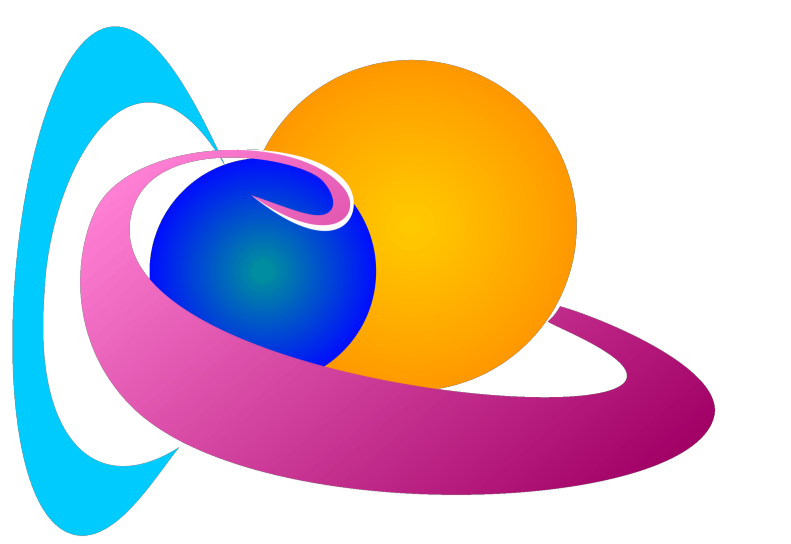


Solar Wind



DOI:10.12942/lrsp-2013-5

DOI: 10.1086/376982



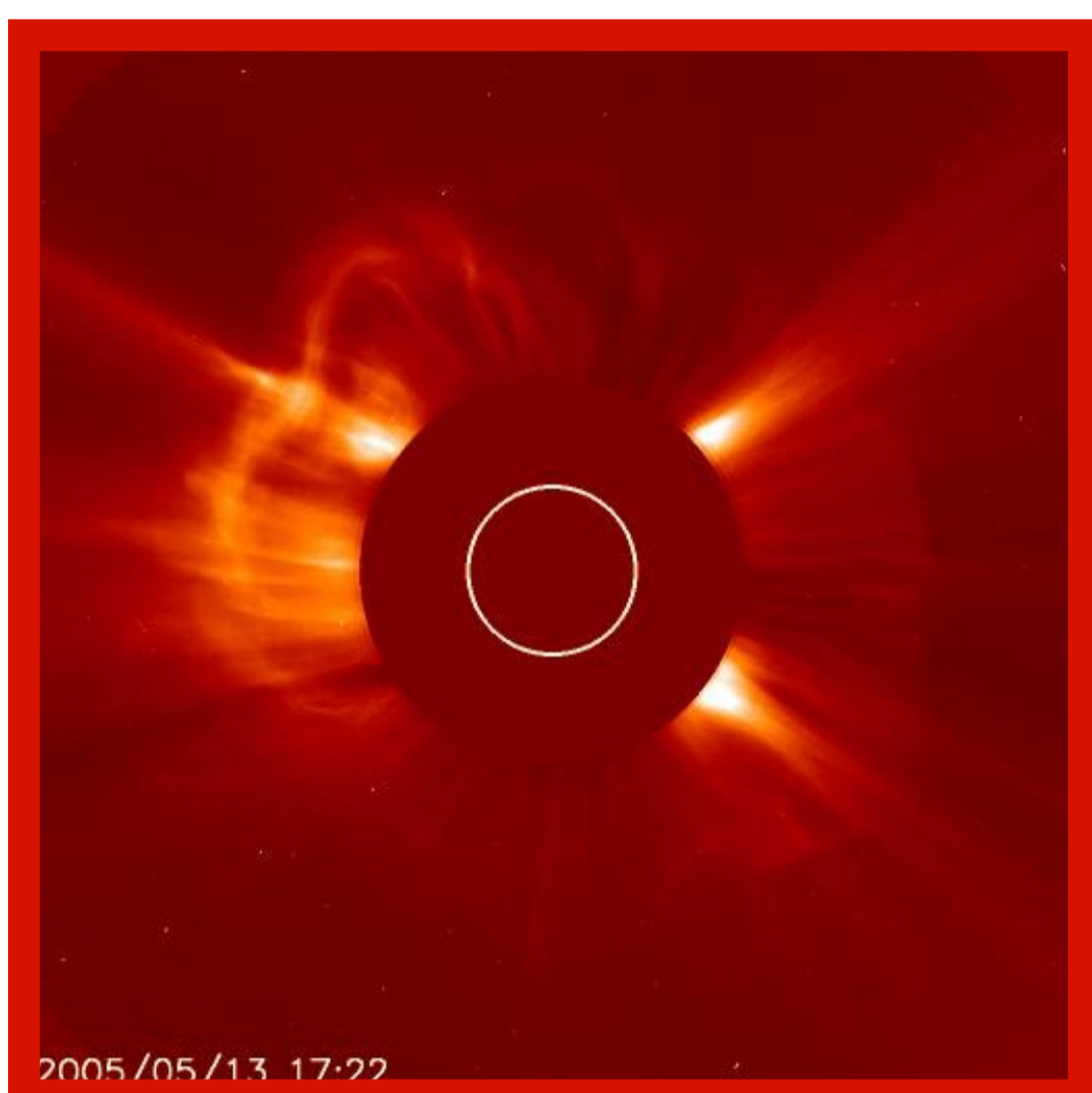
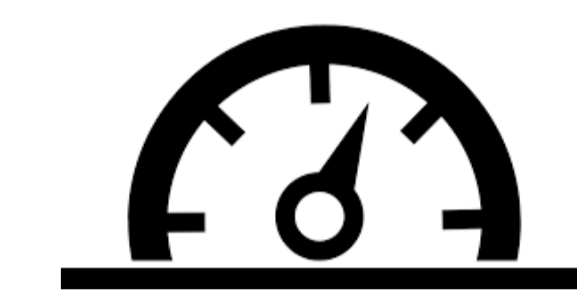
Solar Energy



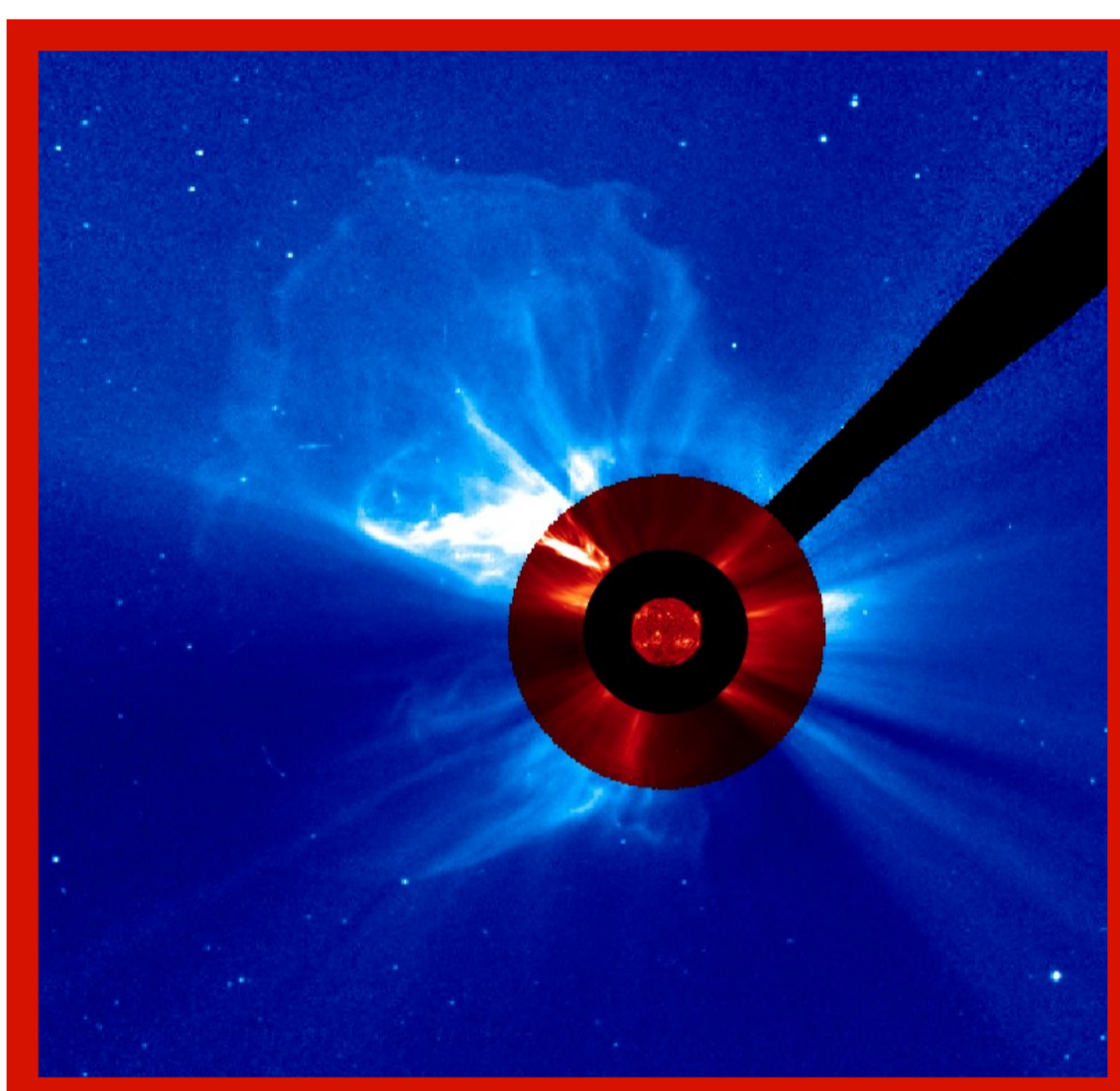
Coronal Mass Ejection Coronal Hole

Days

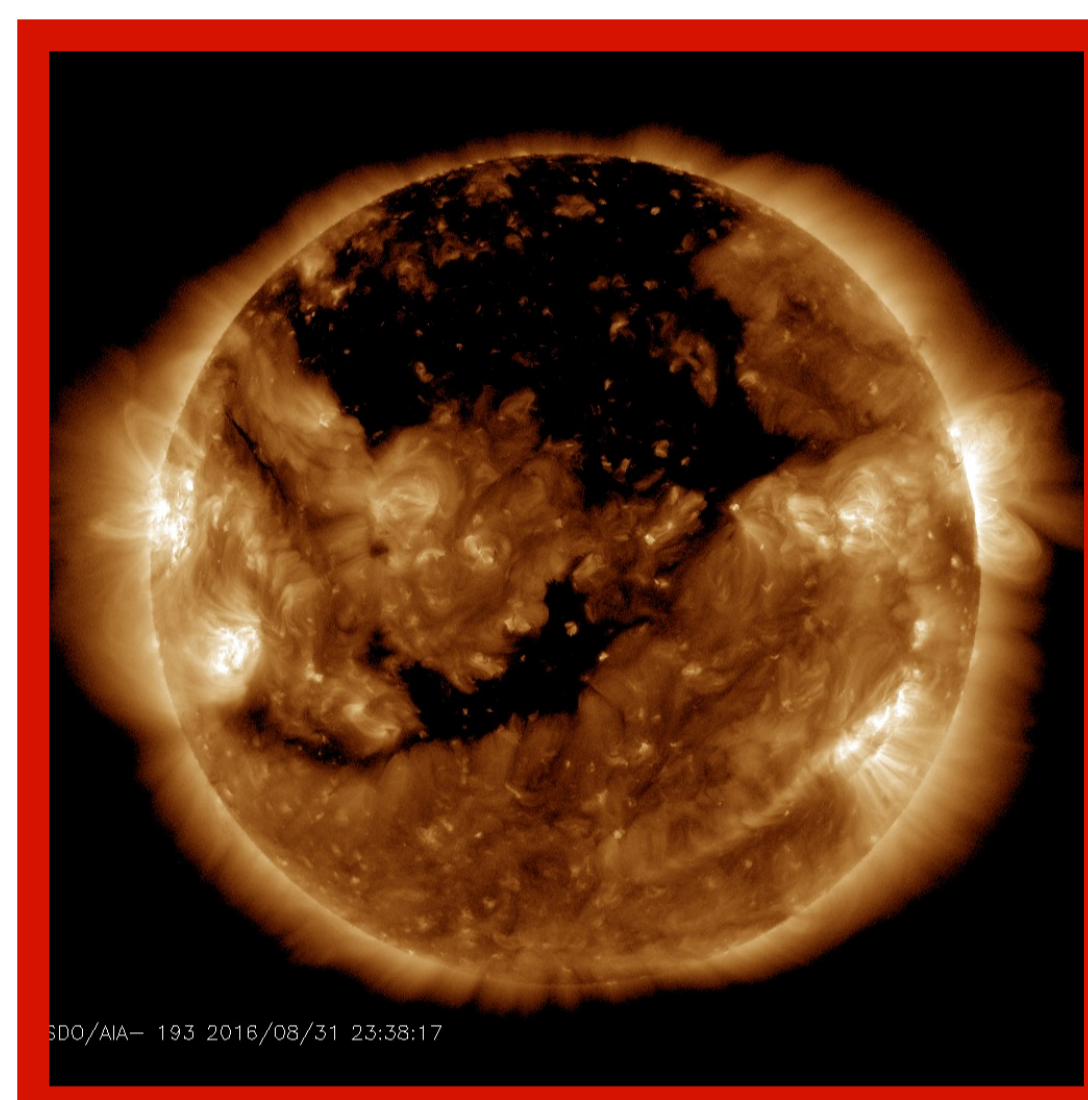
Solar Storms



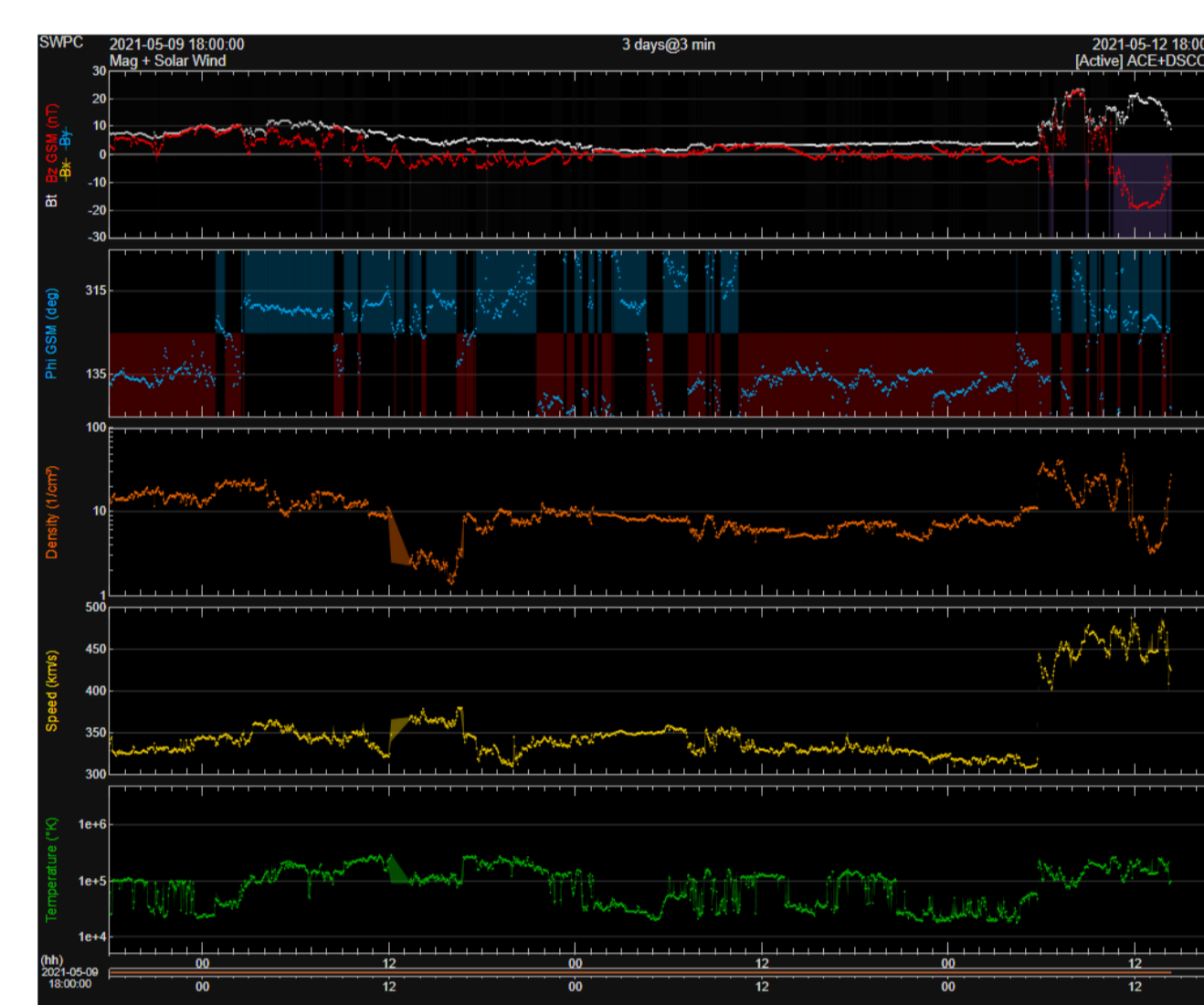
SOHO/LASCO



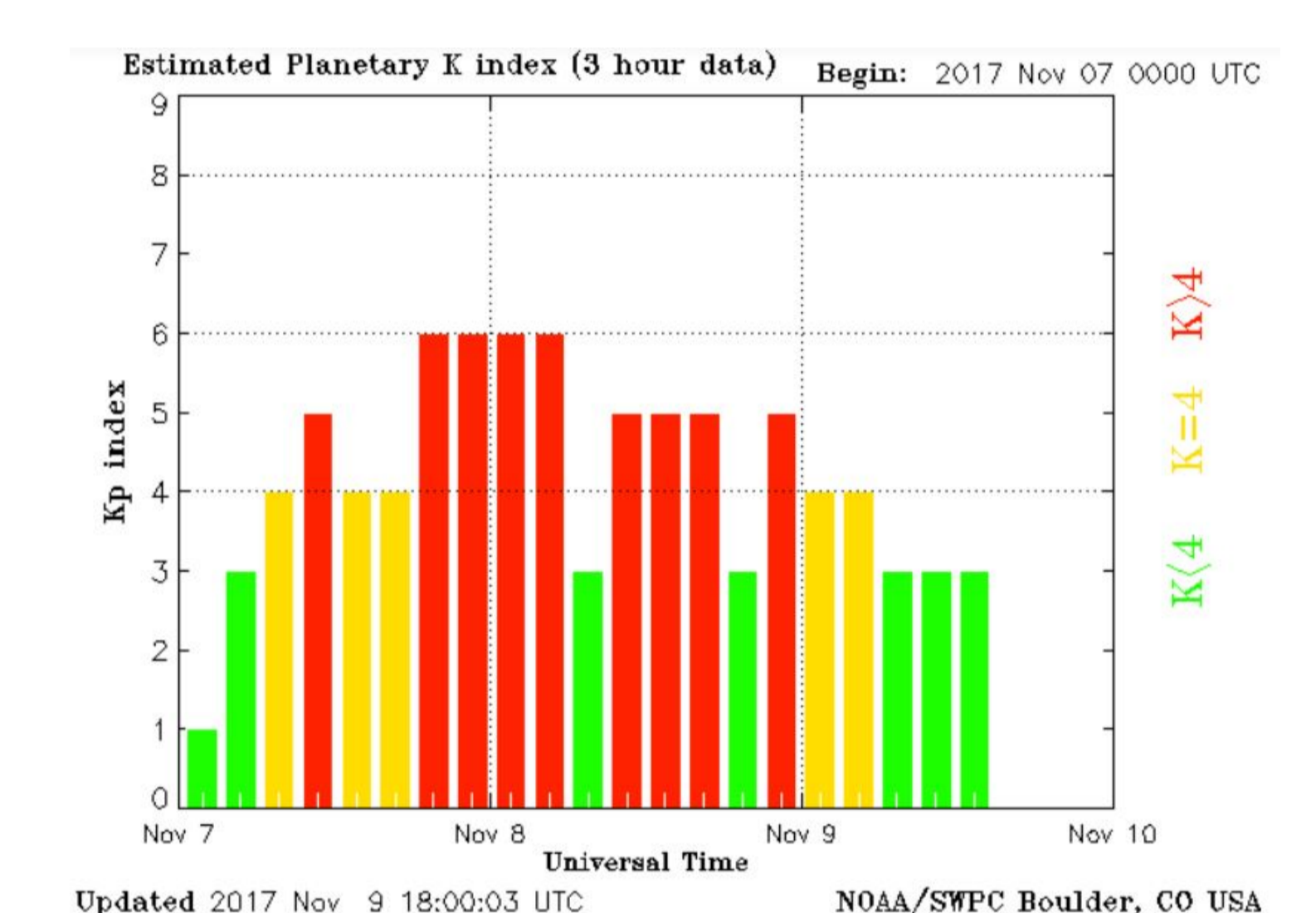
SOHO/LASCO



SDO/AIA



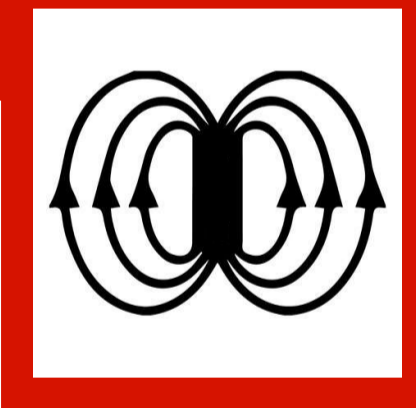
DSCOVR



Kp

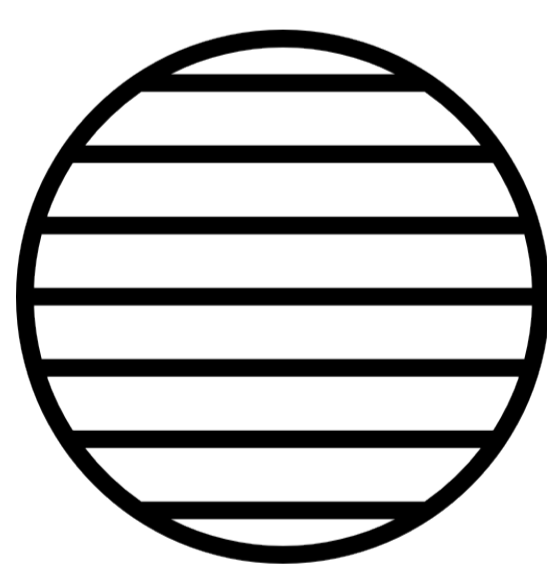


Geomagnetic Storm



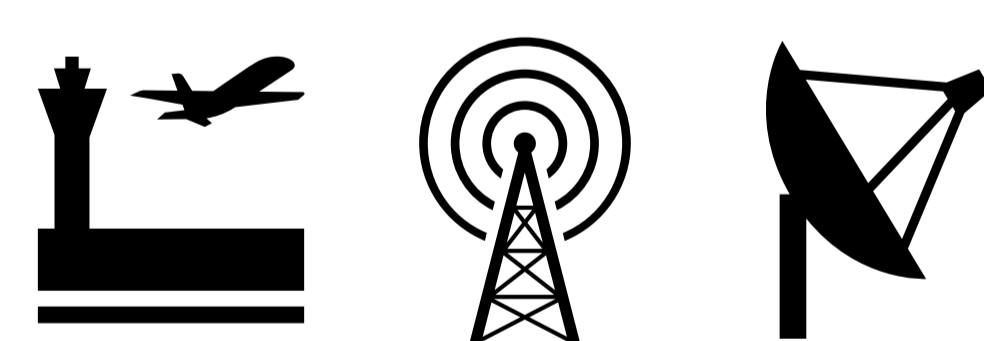
Space Weather

Area of Impact



Latitude

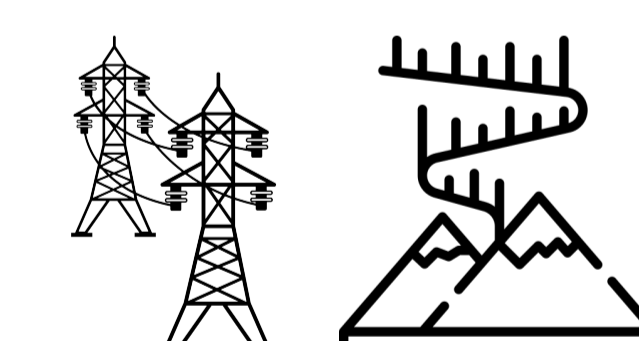
Effects



Radio Disturbance



Positioning
Navigation



Power grid
Aurora

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 | 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.swpc.noaa.gov/Aurora)