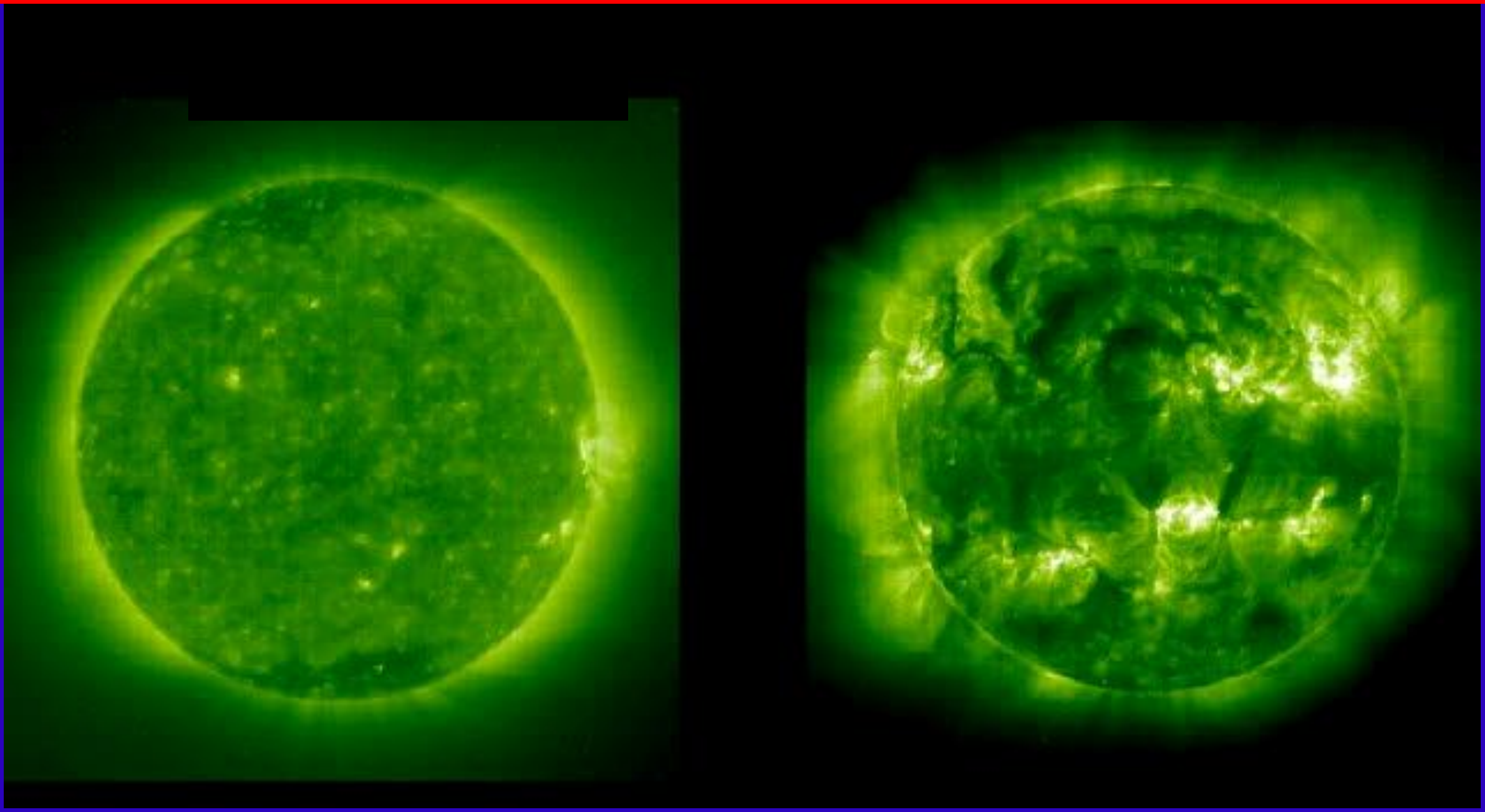
High Frequency Propagation
During the Rising Years of Solar Cycle 25



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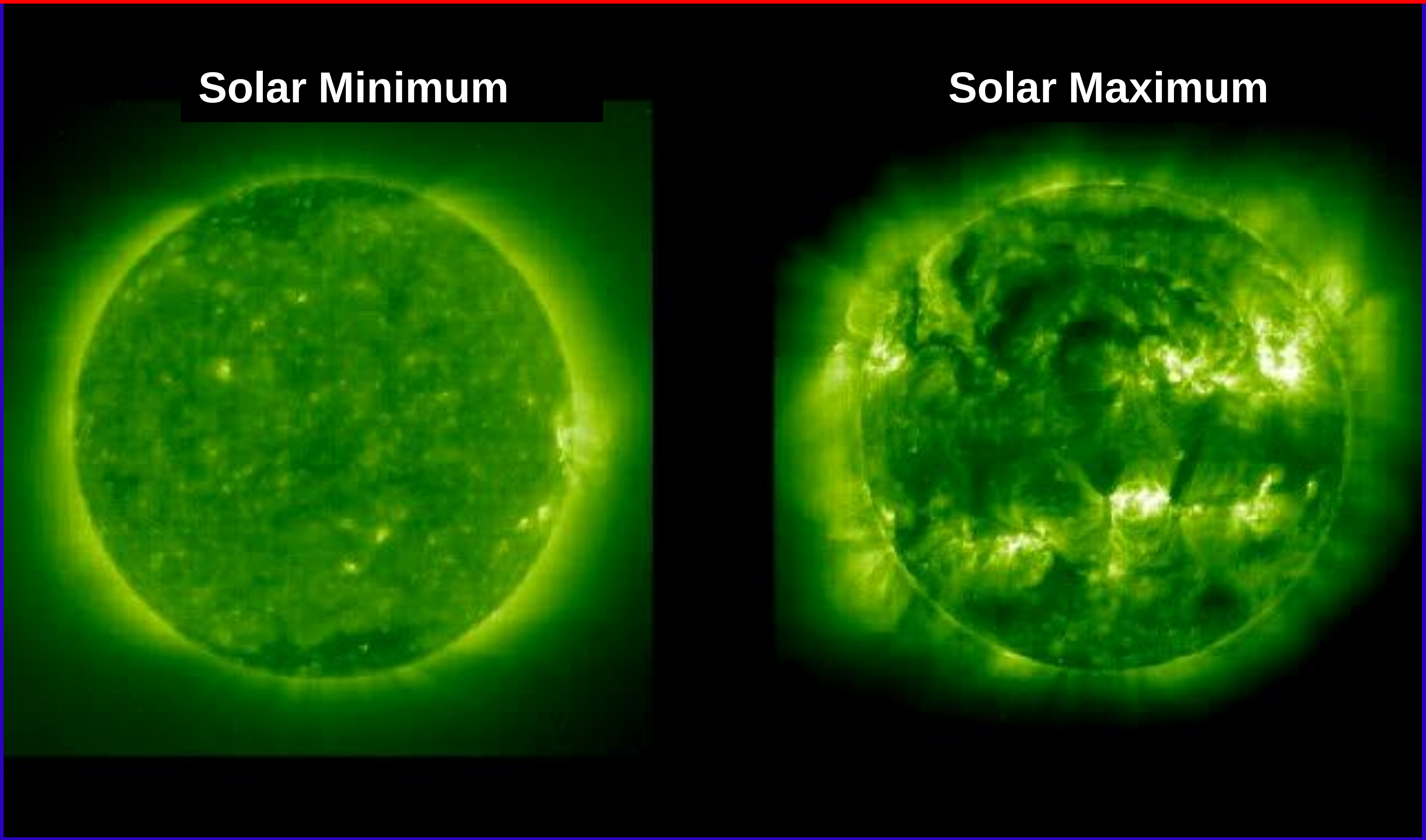
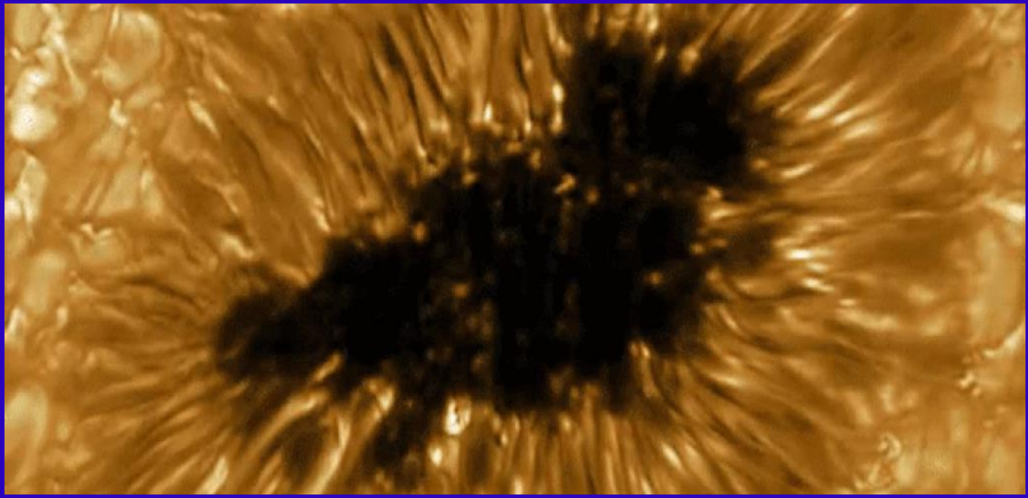
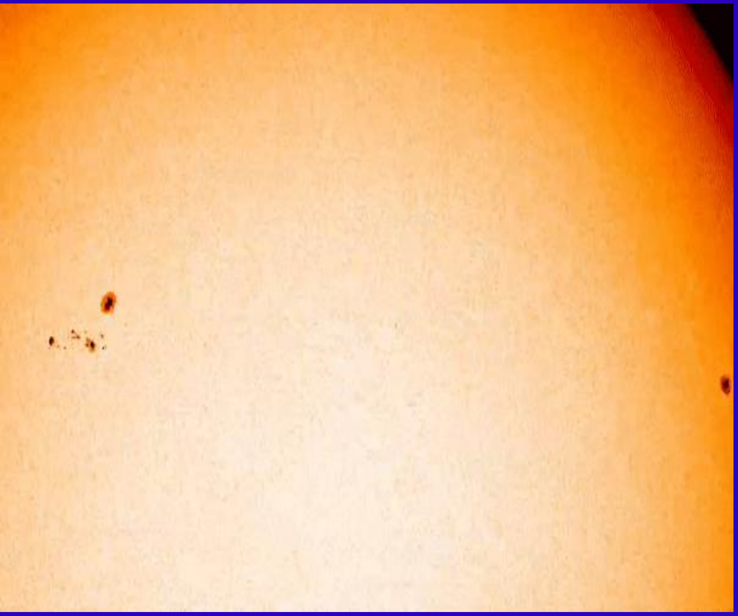
Increasing Extreme Ultraviolet Radiation During the Rising Years of Solar Cycle 25



Improves long distance propagation on the higher bands

More Frequent, More Energetic Sunspots and their <u>active regions</u>



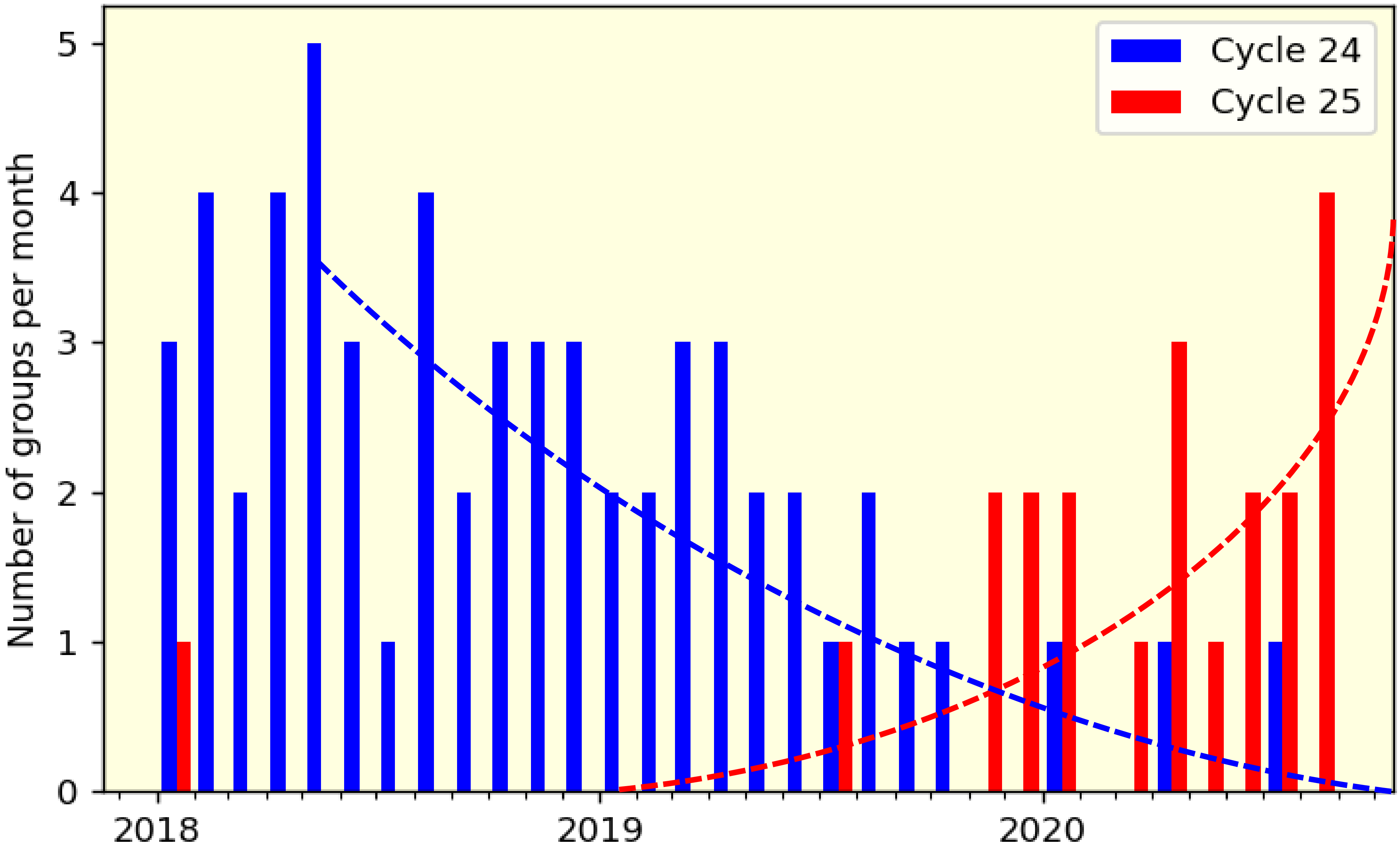


Active regions radiate:

- ionizing ultra violet light
- highly energetic plasma from fast CMEs
- highly energetic hard x-rays from solar flares

Steadily Increasing Solar Cycle 25 Sunspot Activity

the last solar cycle 24 sunspot was on July 4, 2020



Higher Sunspot Numbers
significantly improve long distance propagation
-- except on 160, 80 and 40 meters --

Higher sunspot numbers affect the F2 region
much more than any other ionospheric region

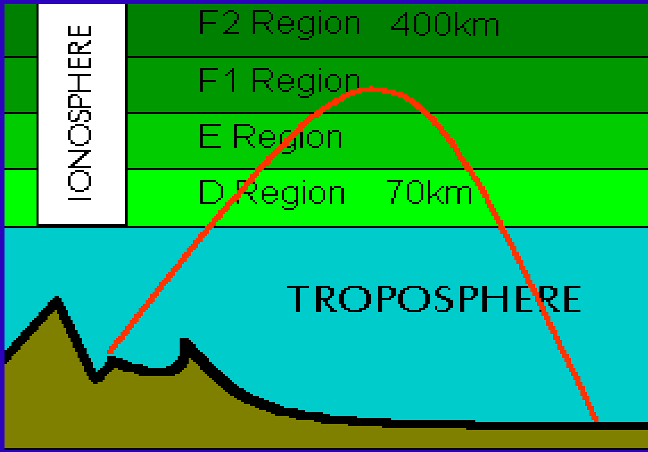
Higher sunspot numbers *usually* greatly increase
the probability of long distance propagation
- from October through May
- on 15 and 10 meters during daylight and evening hours
- on 20 meters during the night

Higher sunspot numbers also increase the frequency and intensity of:
- severe geomagnetic storms
- sudden ionospheric disturbances

Day and Night F1 and F2 Variability

The F2 region is the only ionospheric region providing 24 hour long distance HF propagation

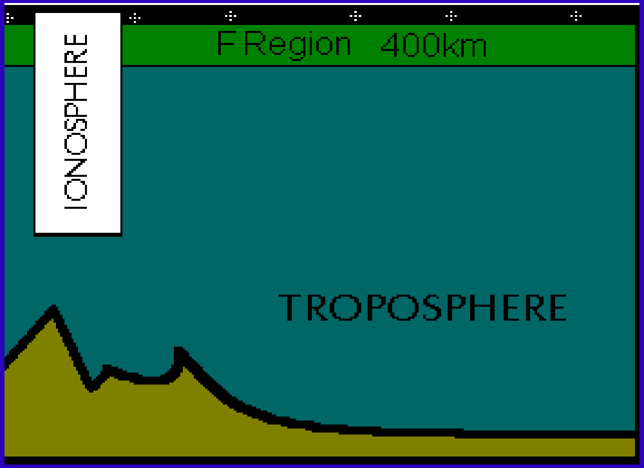
F2 ionization varies greatly with time of day, season, geomagnetic storms
and during the phases of the solar cycle



Day

F2 ionization is greatest during daylight hours

The F1 region is mostly a summer daytime region causing absorption of low angle 20 meter long distance propagation



Night

The F1 and F2 regions merge at night

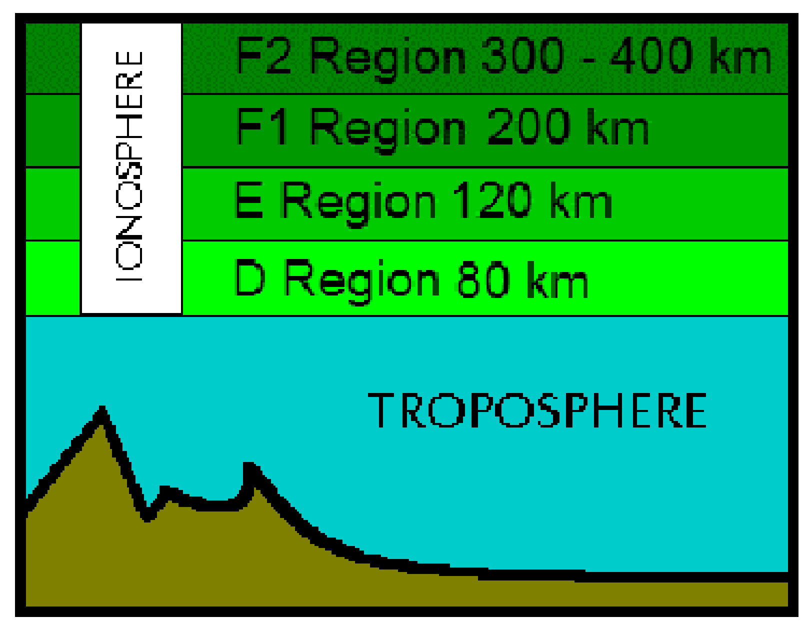
The F2 region is significantly weaker at night causing significantly reduced MUFs especially during the winter and during solar minimum

Summer Night Time F2 Propagation

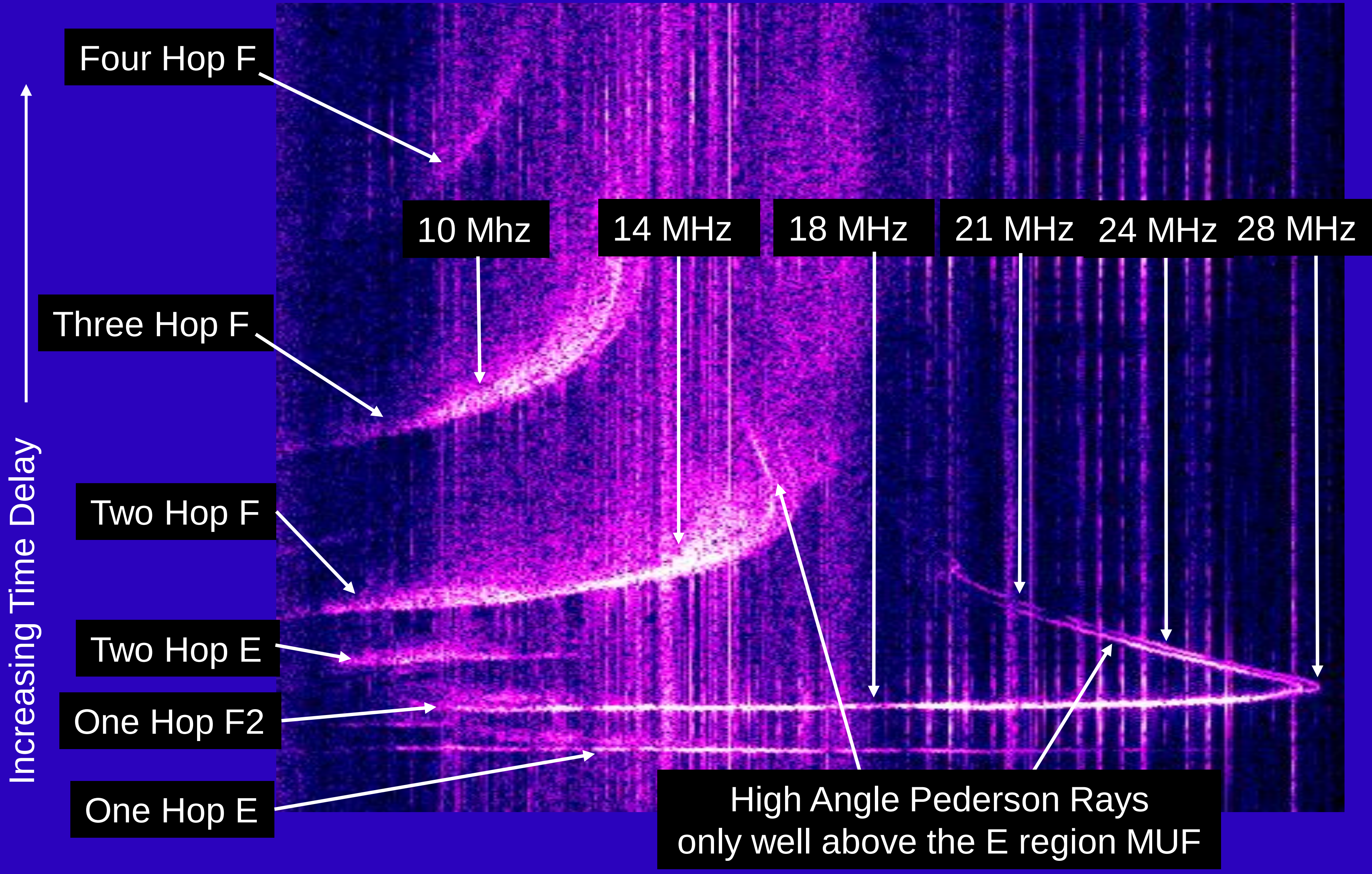
E region and F1 region blanketing and deviative absorption during the summer end several hours before sunset

After sunset in the summer,
the F1 region combines with the F2 region to produce a lower altitude, less densely ionized night time F2 region
at 250 to 300 km altitude

The night time F region is less densely ionized and has lower MUFs than the daytime F2 region



Multi-Path Ionospheric Propagation as detected by an *oblique* ionogram

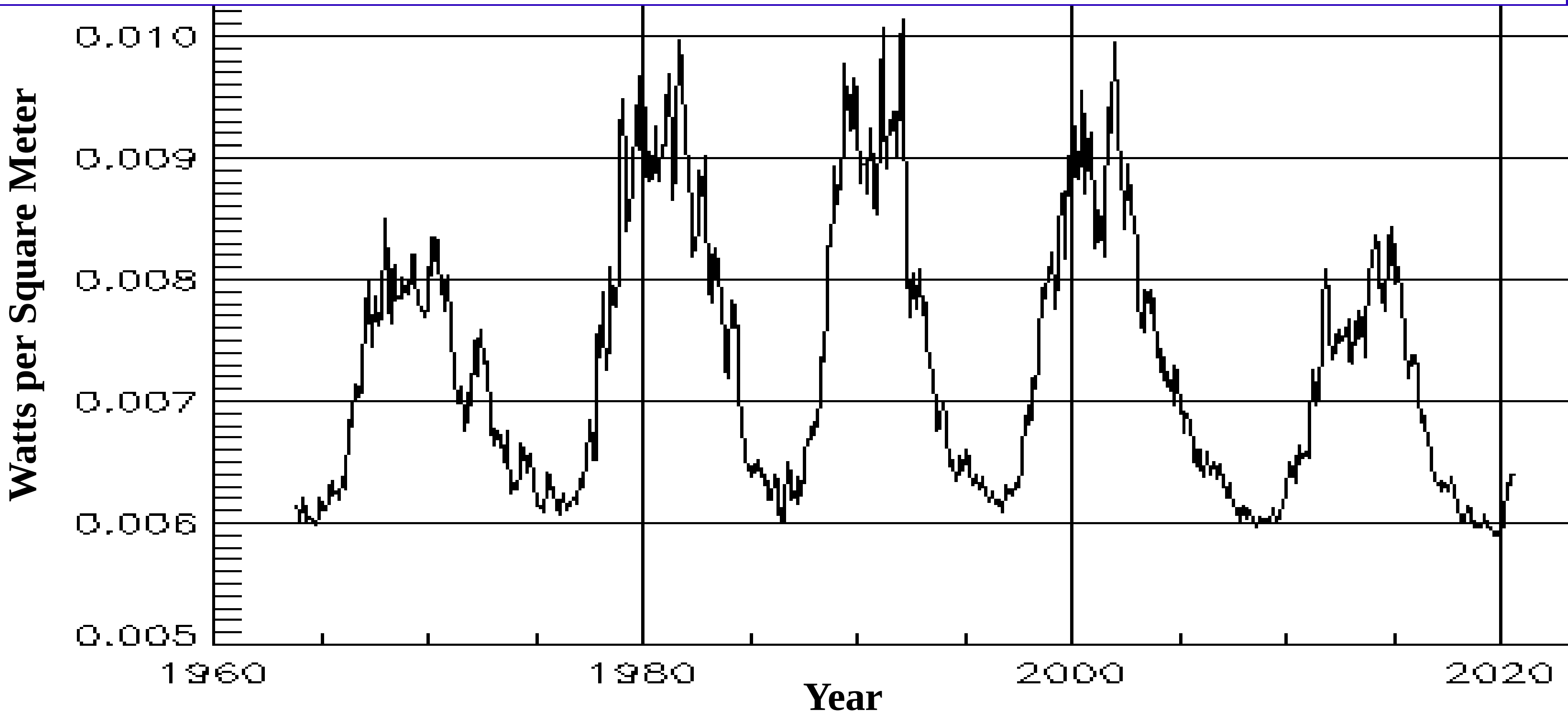


Increased Mid-Latitude D Region Absorption

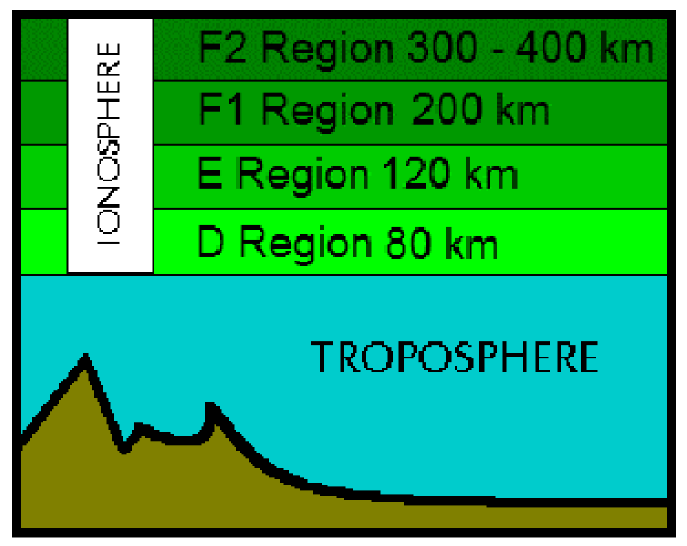
caused by 30-50% increase in far ultraviolet radiation

Causes D region absorption to persist later into the afternoon degrading 80 and 40 meter late afternoon DX propagation

27 day average FUV solar flux measured in watts per square meter



E Region Absorption and Blanketing of low angle long distance F2 propagation



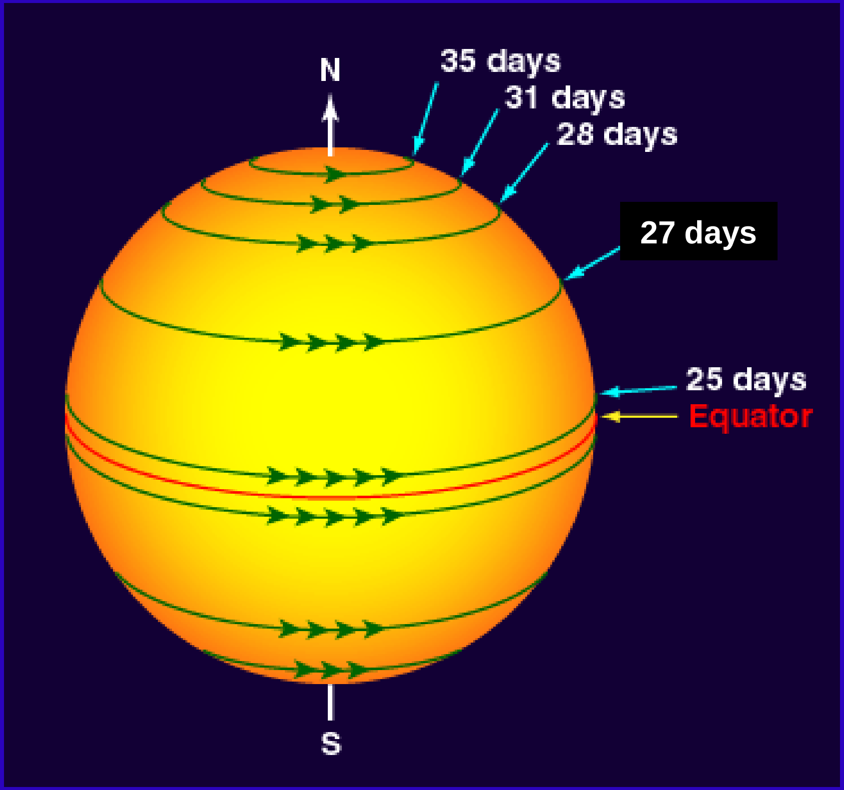
Absorbs and blankets low angle
40 meter long distance F2 propagation
until late afternoon during the years
near solar maximum

Absorbs and blankets low angle
80 meter long distance F2 propagation
until early evening -- and sometimes much later --
during the years near solar maximum

Residual night time E region ionization
absorbs and blankets low angle 160 meter F2 region
propagation throughout the year near solar maximum

27 Day Recurrence of Sunspots and Geomagnetic Disturbances

27 day recurrence of solar events becomes more apparent as sunspots become persistent features on the visible solar disk



Caused by the nominal 27 day (viewed from Earth) solar rotation period at geo-effective solar latitudes

Improved 10 Meter Propagation
from increased extreme ultraviolet radiation

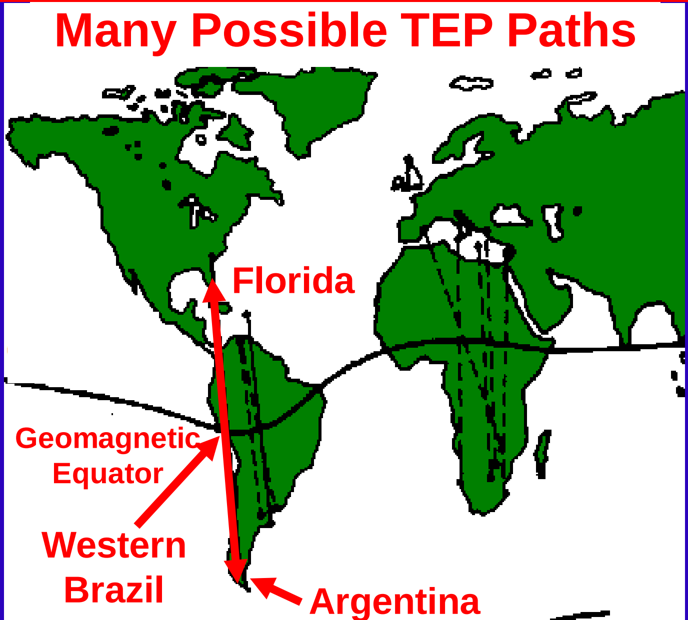
More reliable, more frequent and longer duration DX openings
-- except during the summer --

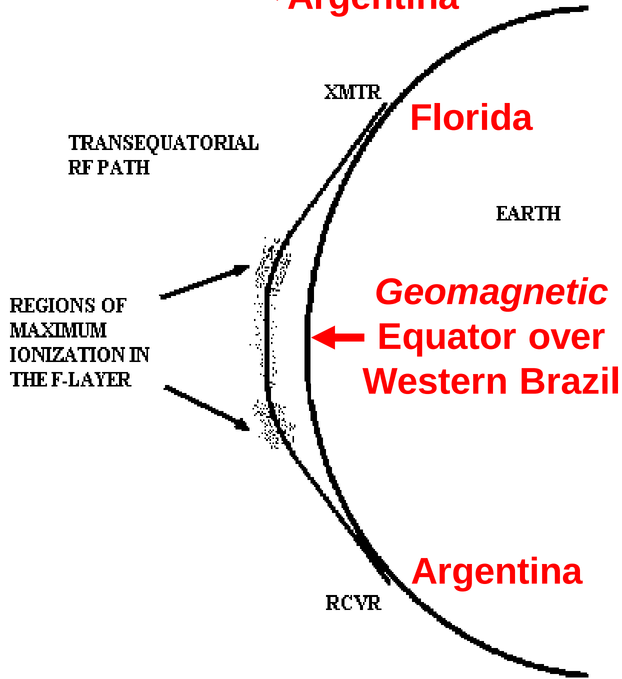
Occasional 10 meter long path openings
-- e.g., from the eastern USA to southeast Asia and Japan --
during spring and fall at about 1300-1400Z

Occasional auroral sporadic-E openings to Scandinavia
-- at about 2000Z --

Trans-Equatorial Propagation - TEP

- The F2 region is tilted and much more intensely ionized:
- - 10 to 20 degrees north and south of the geomagnetic equator
  - from about 1500 to 1900 local solar time at the F2 region reflections
- TEP propagates across the geomagnetic equator and into the opposite hemisphere with enhanced signal strength because there is no intermediary ground reflection
- Stations within about 3000 miles of the geomagnetic equator (e.g., Florida and Argentina) routinely propagate via TEP paths
- Stations more than 3000 miles from the geomagnetic equator (e.g., north of Florida) can sometimes couple onto TEP propagation via an additional sporadic-E hop
- Stations communicating via TEP must be at roughly equal distances from the geomagnetic equator





Improved 15 Meter Propagation

from increased extreme ultraviolet radiation

More reliable, more frequent and longer duration DX openings
throughout the year

More reliable, more frequent long path openings
-- except during the summer –

Occasional auroral sporadic-E openings to Scandinavia
-- at about 2000Z --

Long Path Propagation

Enhanced long distance F2 propagation
between widely separated points
especially near the daylight-darkness terminator

Improved 20 Meter Propagation

from increased extreme ultraviolet radiation

More reliable, longer duration daytime DX
-- except during the summer --

More reliable, more frequent long path openings

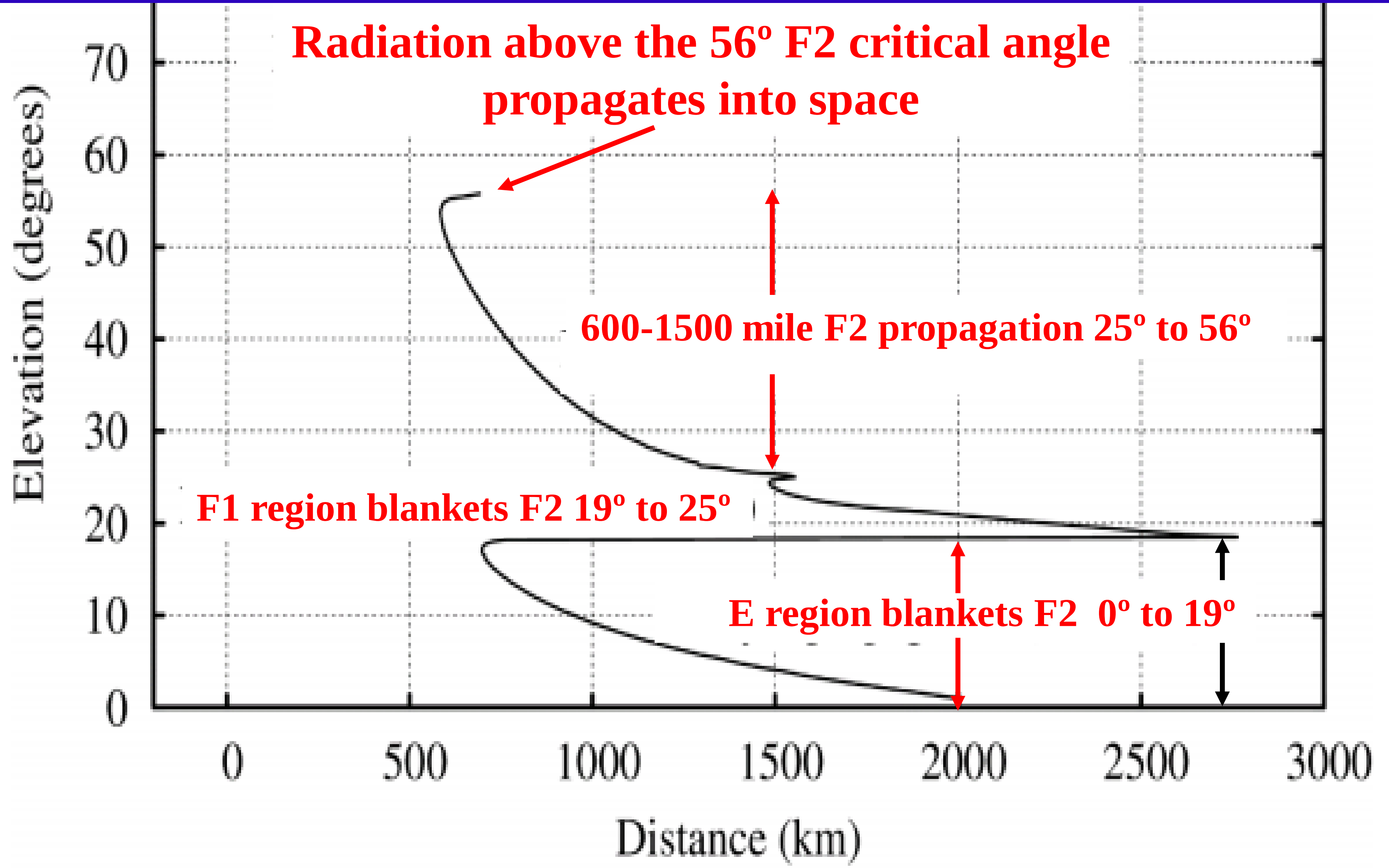
More reliable, more frequent and longer duration nighttime DX year round

Degraded Summer Mid-Day 20 Meter Propagation from increased extreme ultraviolet radiation

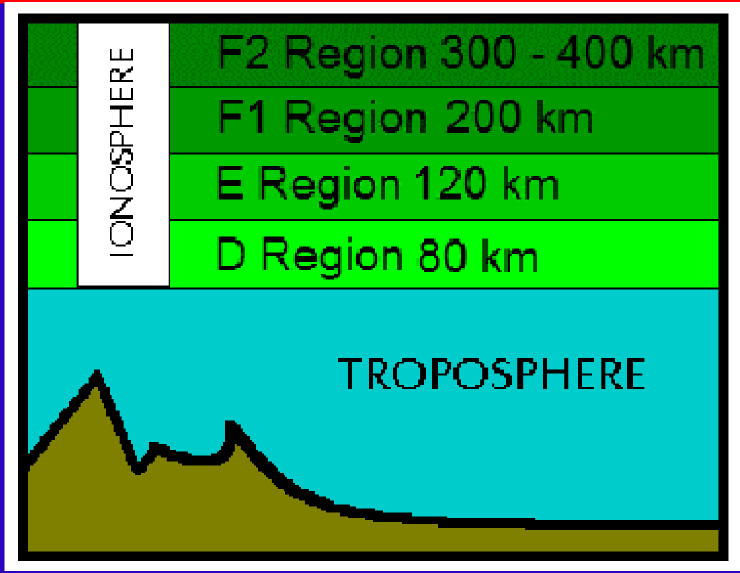
Degraded F2 propagation during mid-day during the summer caused by F1 region absorption and blanketing of F2 propagation

The E and F1 Regions Blanket F2 Propagation

20 meters noon local time summer low SSN



The F1 Region Absorbs and Blankets 20 Meter Daytime F2 Propagation During the Summer



During summer daylight hours the F region ionizes into distinct F1 and F2 regions:
- F2 region at 300 to 400 km altitude
- F1 region at 200 to 300 km altitude

The weakly ionized F1 region occurs only during daylight hours
- every day during the summer
- some days during the late spring and early fall

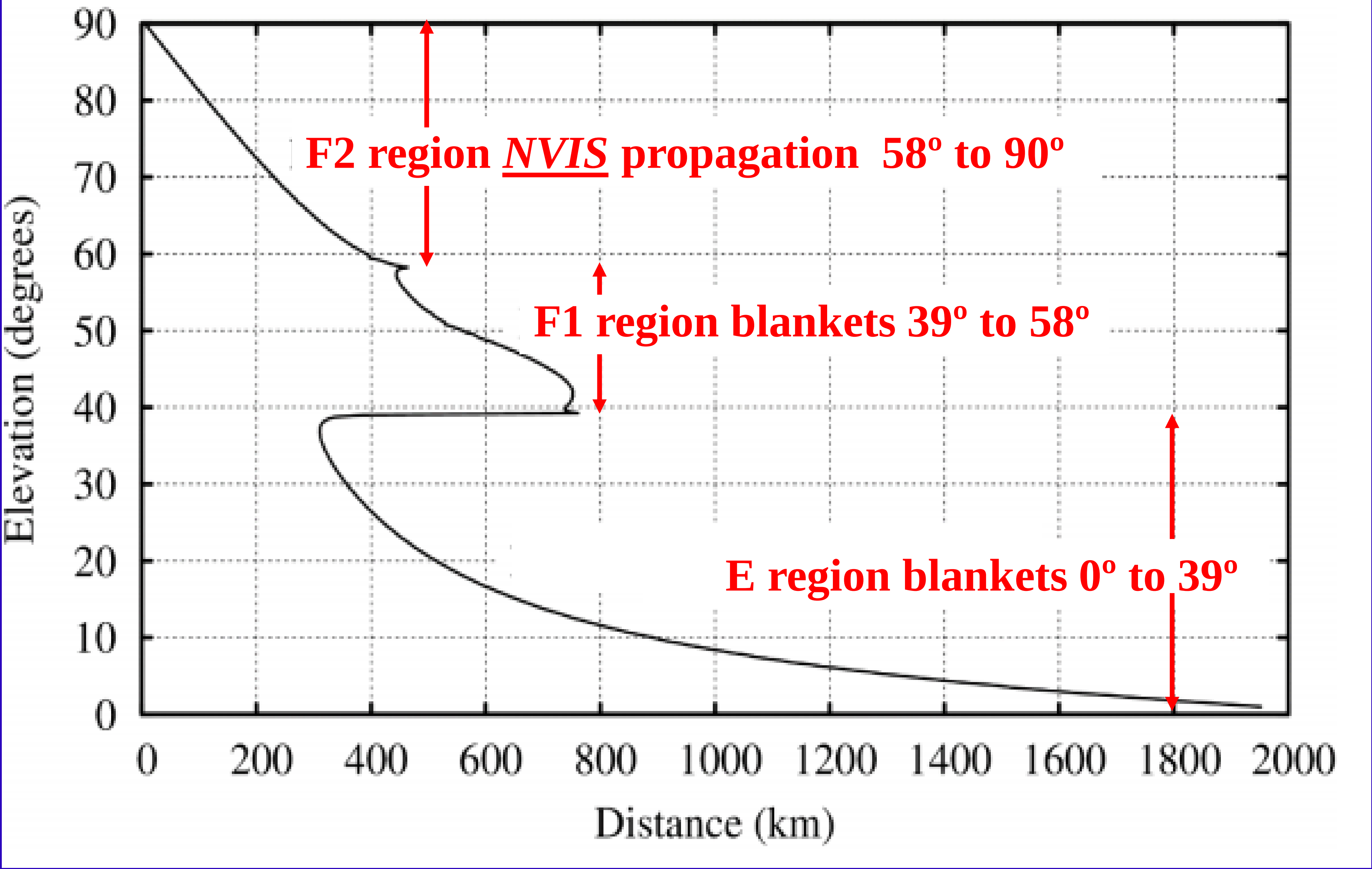
The F1 region significantly degrades 20 meter long distance propagation during summer mid-day hours
- blankets low angle long distance F2 propagation, and
- absorbs higher angle long distance F2 propagation

Degraded 40 Meter Propagation
from increased extreme ultraviolet radiation

- increased D region absorption until late afternoon
- increased E region absorption and blanketing of F2 propagation until just before sunset caused by increased residual E region ionization

The E and F1 Regions Blanket F2 Propagation

40 meters noon local time summer low SSN



Degraded 80 Meter Propagation

from increased extreme ultraviolet radiation and increased D region absorption in the auroral oval

Increased D region absorption until sunset

More rapid increase in D region absorption at sunrise

Increased E region absorption and blanketing of F2 propagation until late night caused by increased residual E region ionization

Increased D region absorption in the auroral oval caused by increased energetic electron precipitation into the D region after midnight at the propagation path control points in the aurora oval

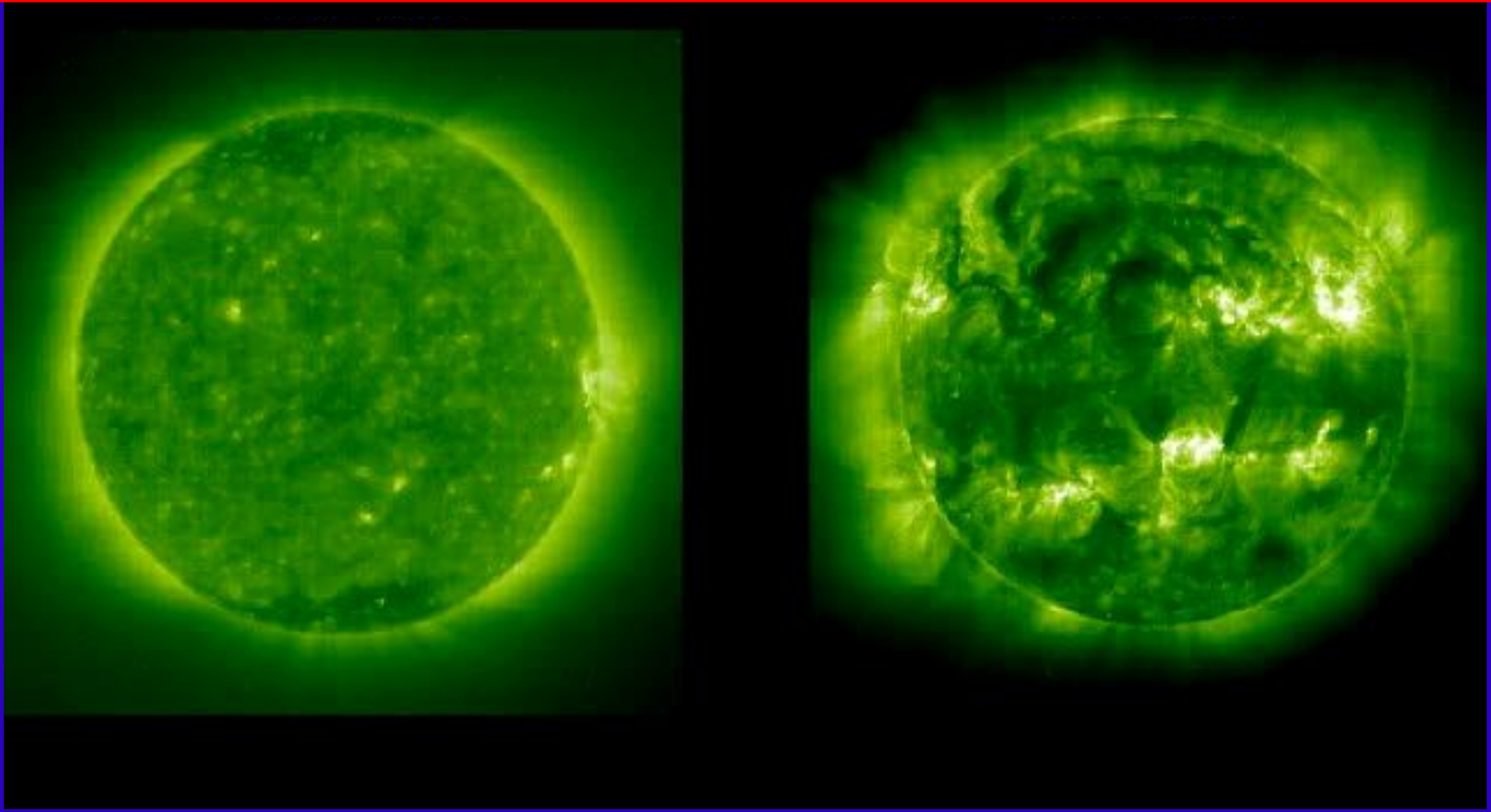
Degraded 160 Meter Propagation

from increased extreme ultraviolet radiation and increased D region absorption in the auroral oval

Increased E region absorption and blanketing of F2 propagation during the evening and early nighttime hours caused by increased residual ionization

Increased D region absorption in the auroral oval caused by increased energetic electron precipitation into the D region after midnight at the propagation path control points in the aurora oval

Less frequent, smaller and shorter duration coronal holes
During the Rising Years of Solar Cycle 25

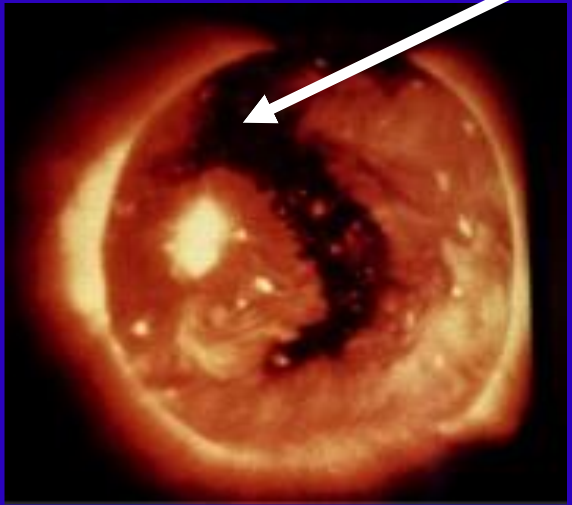


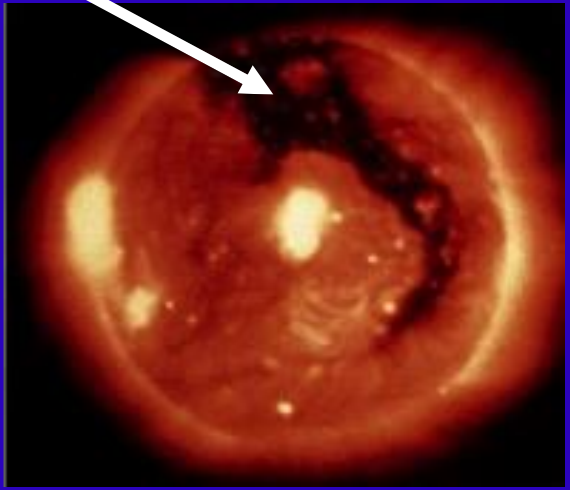
less frequent unsettled to active geomagnetic conditions
caused by coronal holes

Disturbed Geomagnetic Conditions mostly during the years ***before solar minimum***

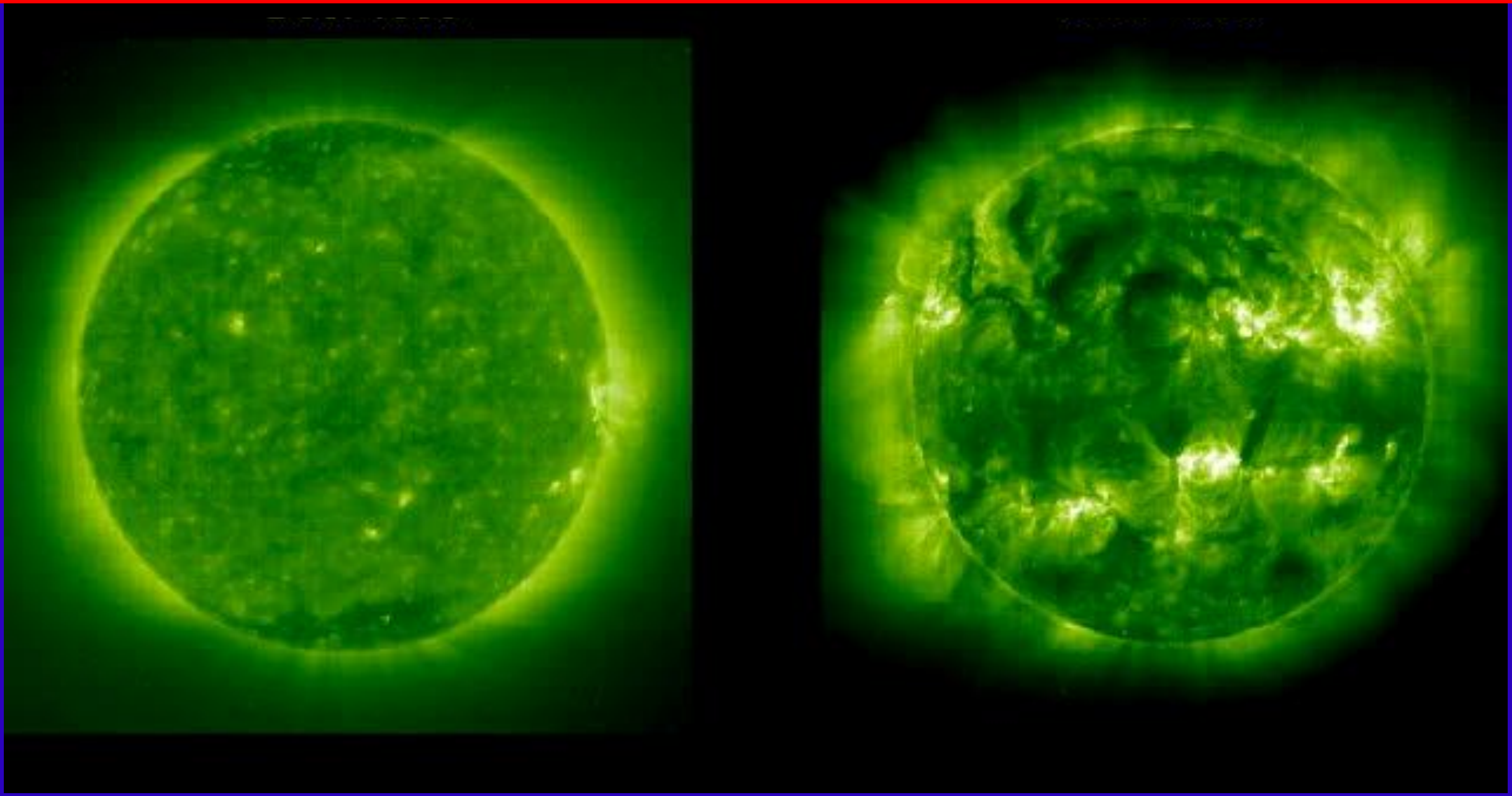
Energetic particles flowing from polar coronal holes
are the primary source of the fast solar wind (>500 km/sec)
that causes unsettled to active geomagnetic disturbances
mostly during the four years prior to solar minimum

Disturbed geomagnetic conditions caused by polar coronal holes
are less frequent after solar minimum
and very infrequent near solar maximum





Less frequent, smaller and shorter duration coronal holes
During the Rising Years of Solar Cycle 25

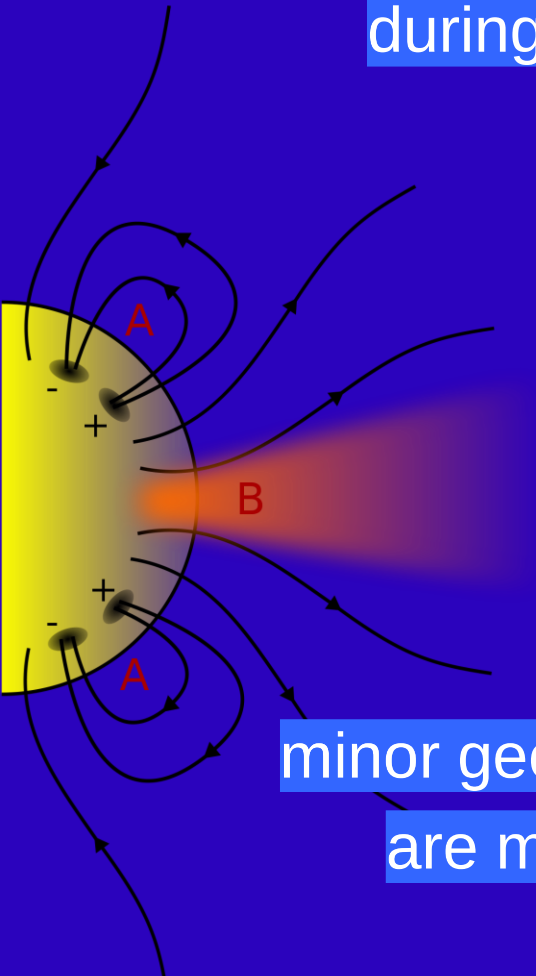


much less frequent minor geomagnetic storms
caused by coronal holes

Minor Geomagnetic Storms
mostly during the years ***before solar minimum***

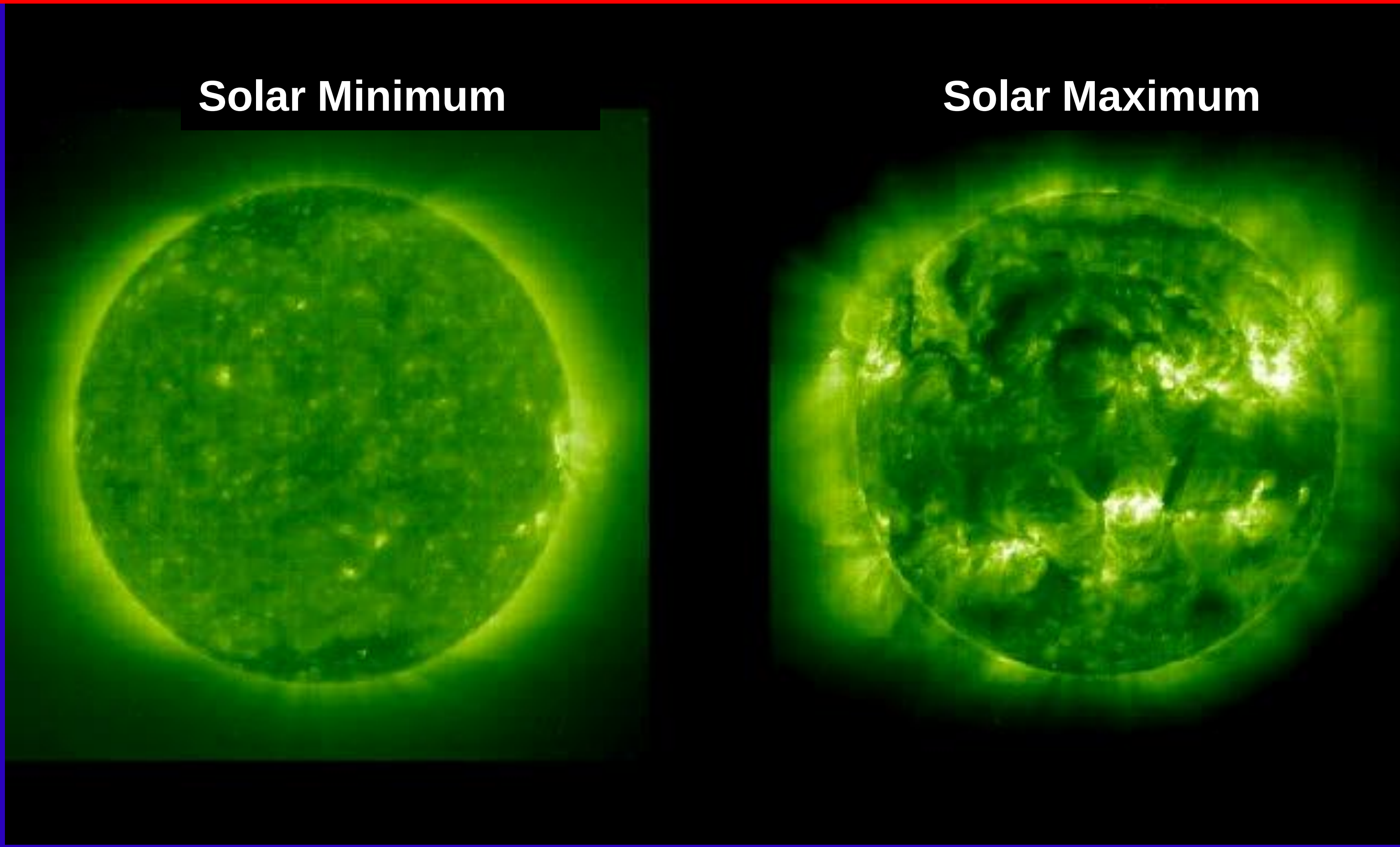
Coronal hole high speed stream interactions with the solar wind cause brief minor geomagnetic storms

during the years leading up to solar minimum



minor geomagnetic storms caused by coronal holes are much less frequent after solar minimum

More Frequent Fast Coronal Mass Ejections During the Rising Years of Solar Cycle 25

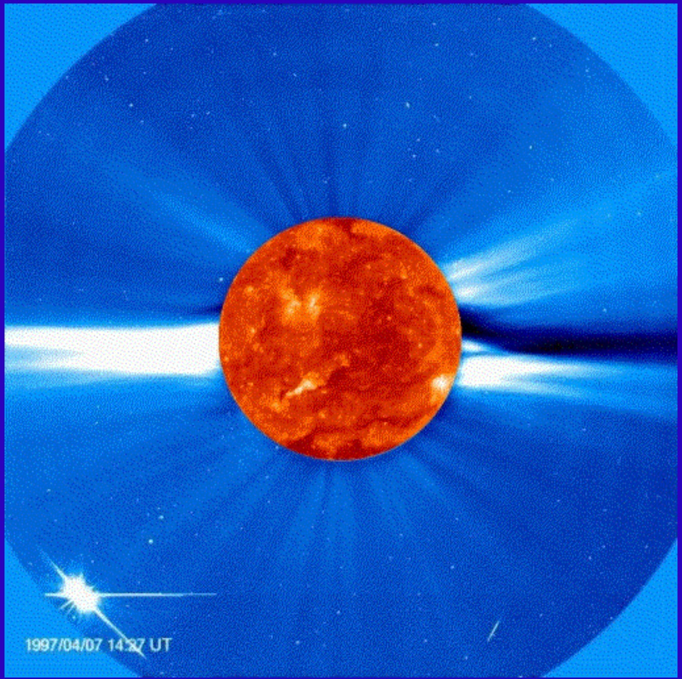


cause more frequent, longer lasting moderate and severe geomagnetic storms

Fast Coronal Mass Ejections (CMEs)
are the dominant cause of geomagnetic storms

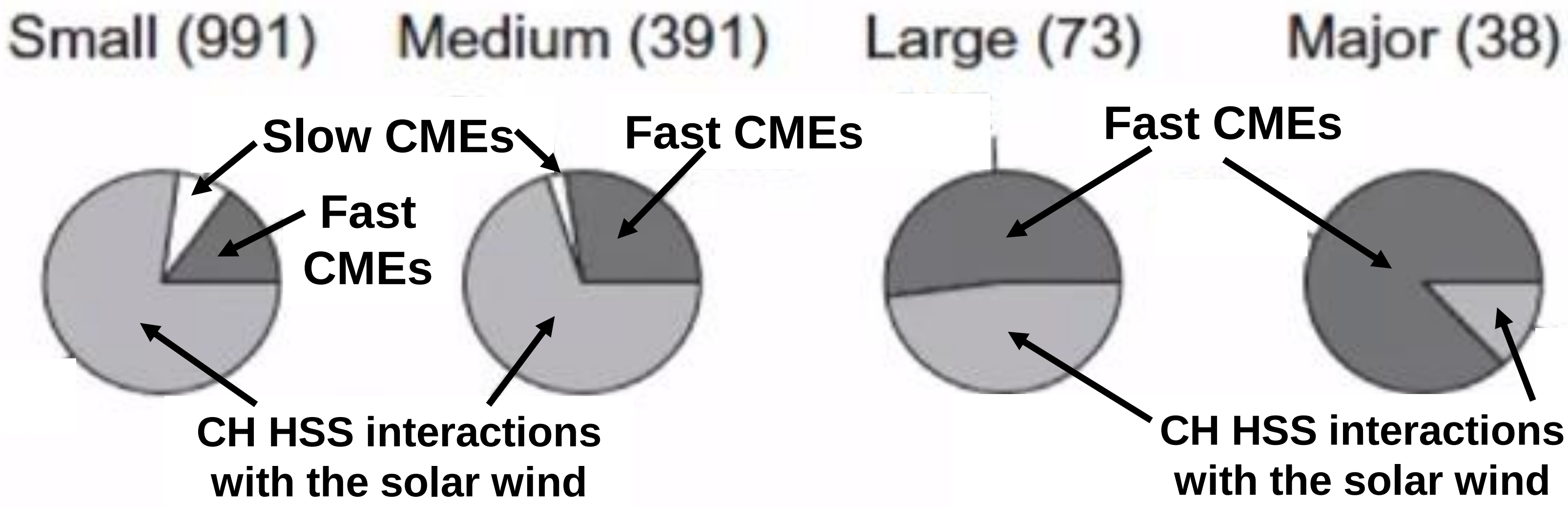
Fast CMEs from solar active regions are the
dominant cause of moderate to severe propagation disturbances

Fast CME impacts are greatly magnified when the interplanetary magnetic field (IMF) persists in a southward orientation
-- opposite to Earth's magnetic field --
for a long period of time

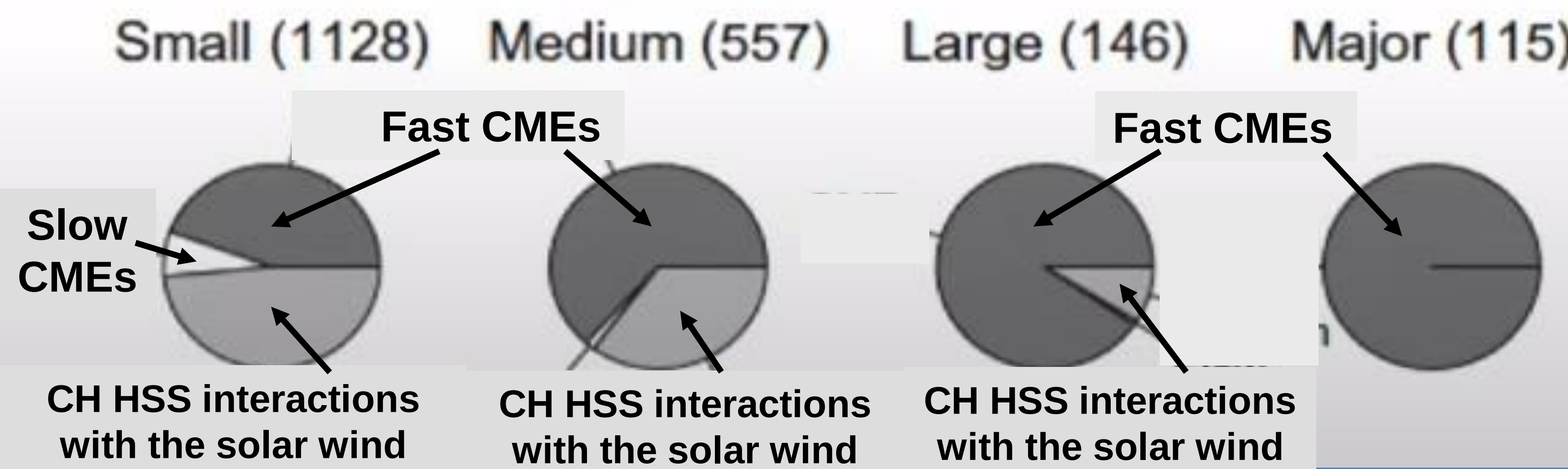


Fast Coronal Mass Ejections are the dominant cause of geomagnetic storms

cause most large and major geomagnetic storms during solar maximum



cause most geomagnetic storms of all sizes during solar maximum



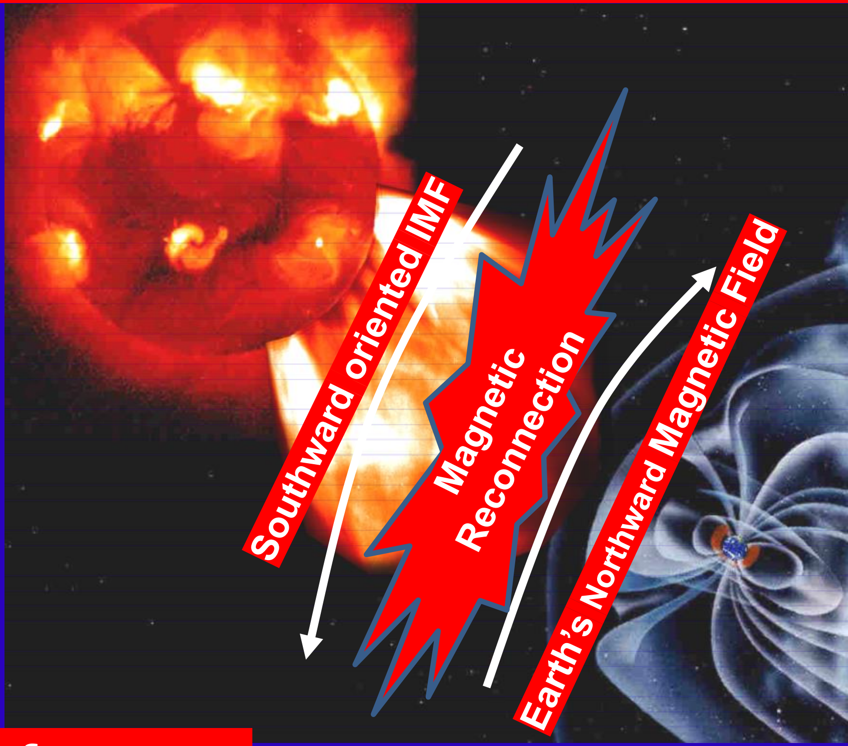
Strong to Severe Geomagnetic Storms
caused by persistent southward orientation of the IMF

Persistent Southward Orientation of the Interplanetary Magnetic Field

causes strong to severe geomagnetic storms when it persists

for an extended period of time

when enhanced by a fast CME

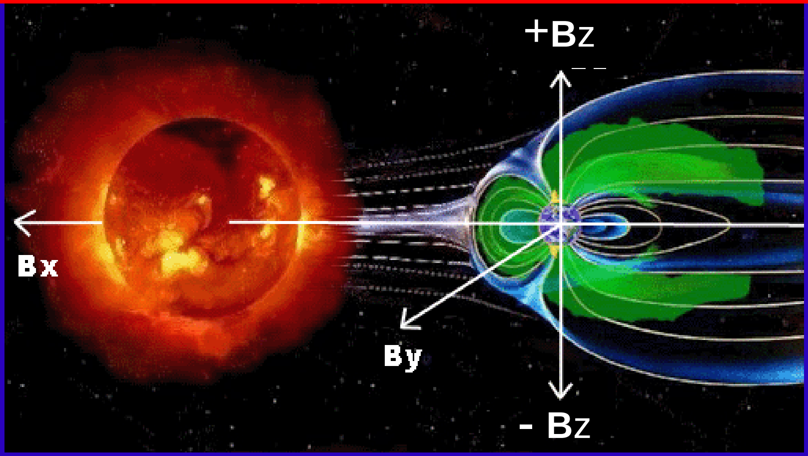


Fast CMEs are much more frequent during the seven most active years of the solar cycle

Severe geomagnetic storms are most frequent:

- during Earth's equinox seasons, and
- when directed toward the Earth from a low solar latitude close to the Sun's central meridian

Southward Orientation of the Interplanetary Magnetic Field (IMF)



When the north-south (Bz) component of the IMF turns southward:

- magnetic reconnection with the Earth's oppositely polarized magnetic field converts its magnetic into kinetic energy, accelerating the solar wind
- accelerated plasma precipitates into the ionosphere on a global scale
- persistent southward oriented Bz can cause severe geomagnetic storms

Storm level	Kp Index	-Bz field strength	- Bz Persistence
Severe	8	100-200 nT	> 4 hours
Strong	7	50-100 nT	3-4 hours
Moderate	6	3-50 nT	2-3 hours
Minor	5	<3 nT	1-2 hours

Geomagnetic Storm Propagation Impacts

Geomagnetic storms are caused by fast CMEs near solar maximum and by interaction between coronal hole high speed streams and the solar wind mostly during the four years before solar minimum

Kp=9 **four days or less per solar cycle**

Impossible HF ionospheric propagation in many areas for at least two days

-- occurs only during the two years near solar maximum --

Kp=8 **about 100 events (60 days) per solar cycle**

Sporadically available HF ionospheric propagation in many areas for one or two days

Kp=7 **about 200 events (130 days) per solar cycle**

Sporadically available HF ionospheric propagation at high latitudes for one or two days

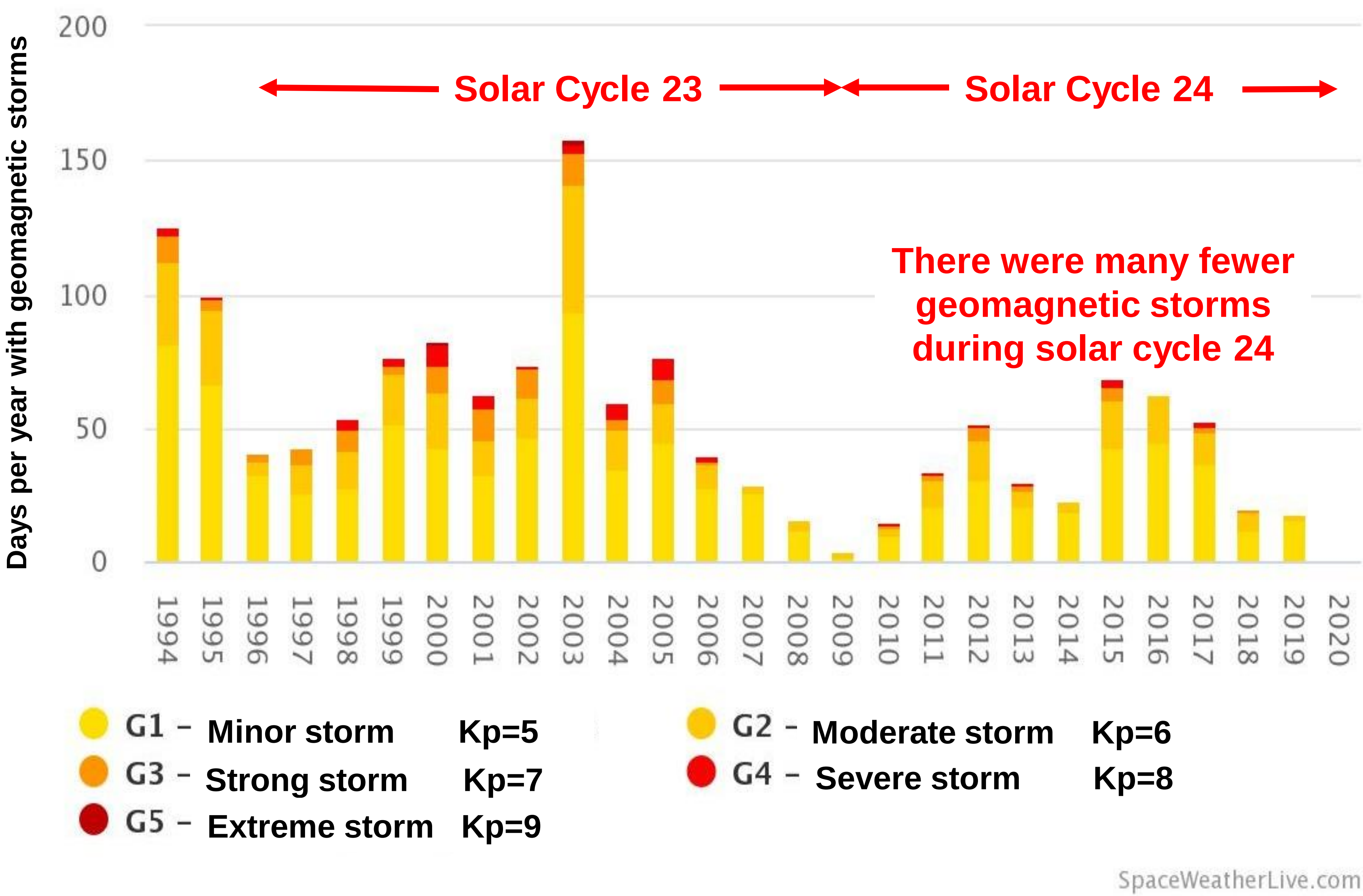
Kp=6 **about 600 events (360 days) per solar cycle**

Unstable HF ionospheric propagation at high latitudes for many hours

Kp=5 **about 1700 events (900 days) per solar cycle**

Unstable HF ionospheric propagation at high latitudes for a few hours

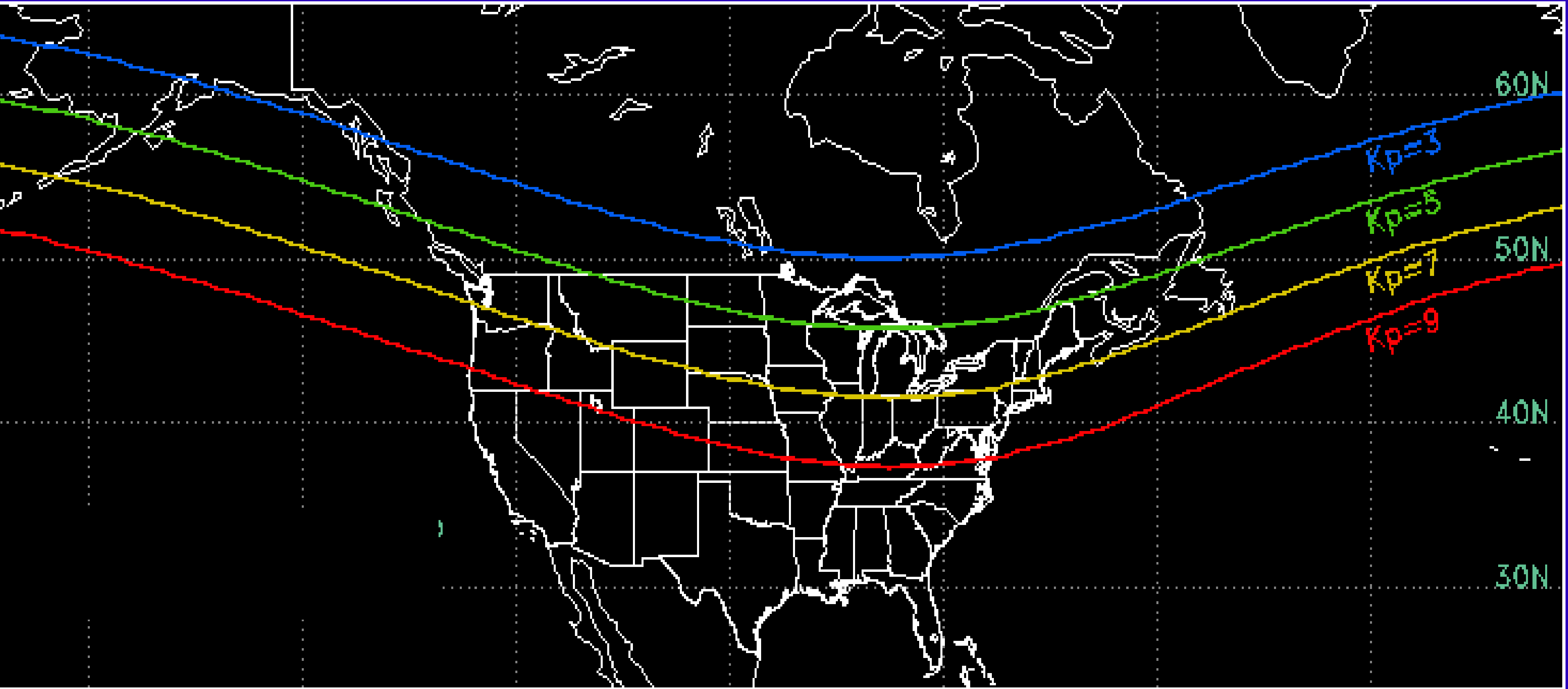
Days per Year with Geomagnetic Storms



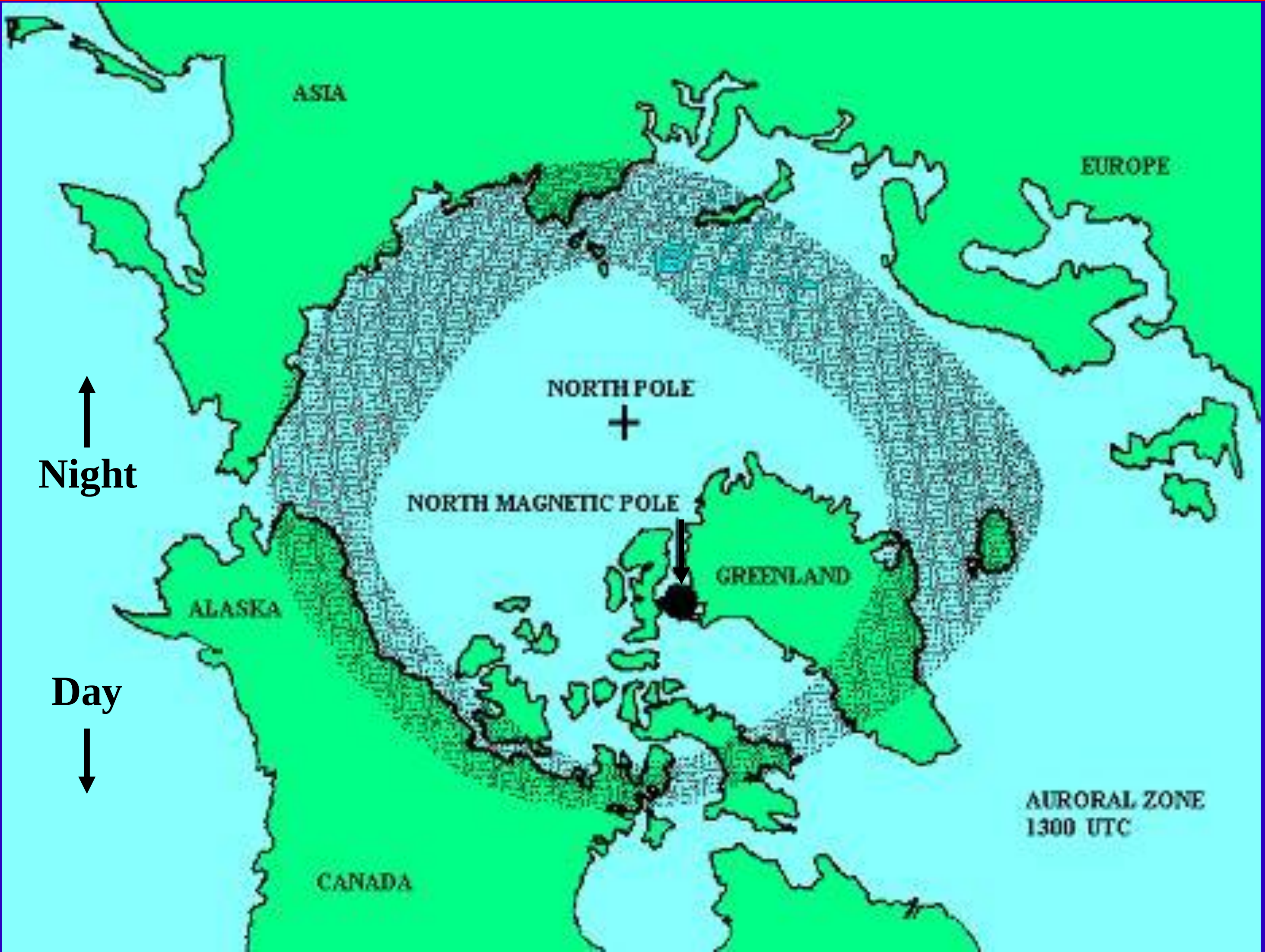
Absorption in the Auroral Oval D-Region caused by geomagnetic storms

Auroral oval absorption intensity, latitude, north-south extent and duration depend on the strength of the triggering geomagnetic storm

Aurora is much more common during spring & fall near solar maximum



The Auroral Oval
during quiet geomagnetic conditions
Planetary Kp Index = 0, 1 or 2



Absorption in the Auroral Oval D-Region caused by geomagnetic storms

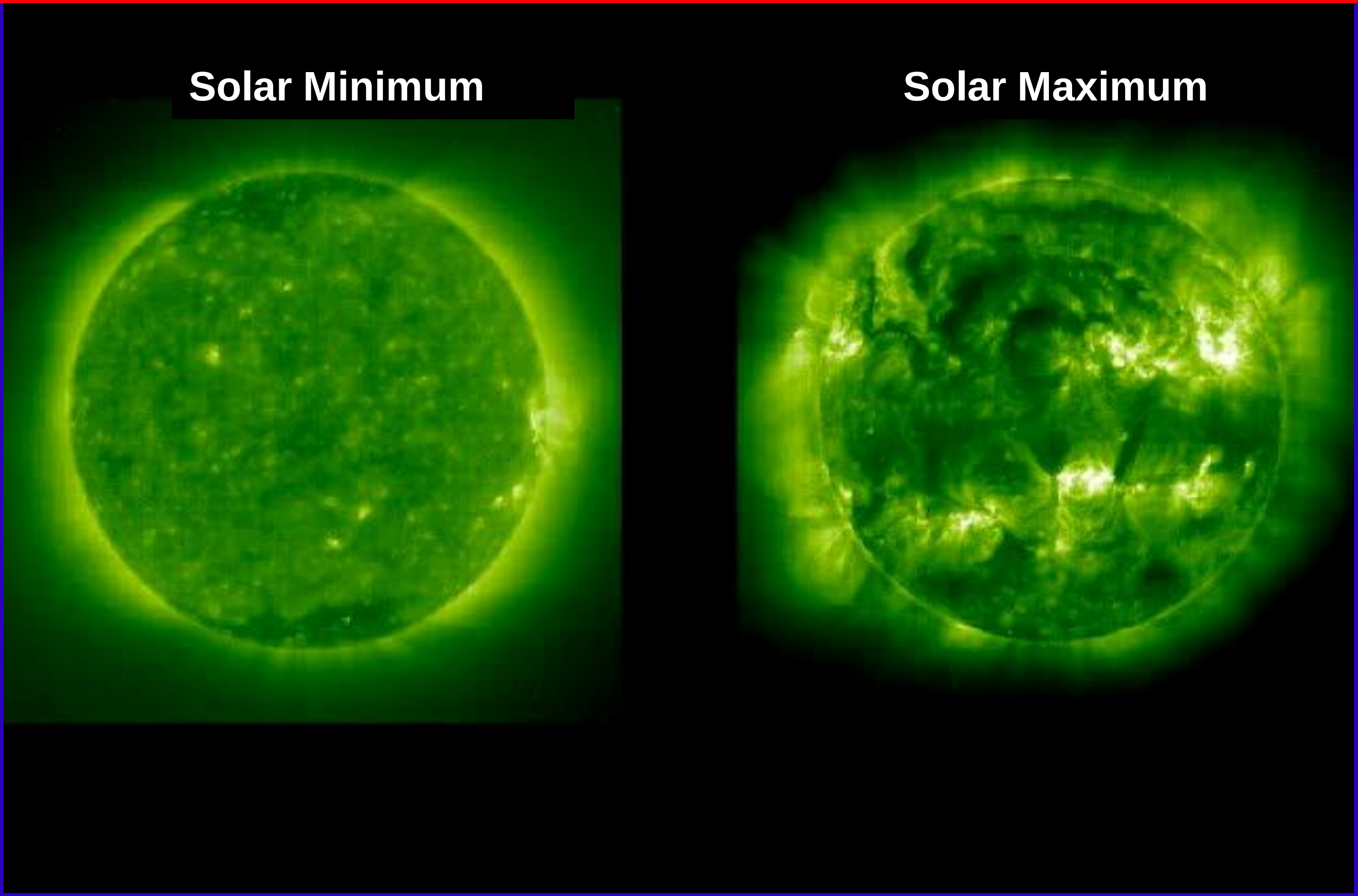
The night time auroral oval moves equator-wards during geomagnetic storms:

- the enhanced solar wind pulls the Earth's nightside open magnetic field lines further toward the equator
- shifting the auroral zone closer to the northern U.S. border

Auroral oval absorption causes by geomagnetic storms begins at about midnight at the reflection points in the auroral oval

After sunrise at the reflection points in the auroral oval normal daytime D region absorption caused by photo ionization is almost always stronger than auroral absorption caused by geomagnetic storms

More Frequent M and X-Class Solar Flares During the Rising Years of Solar Cycle 25



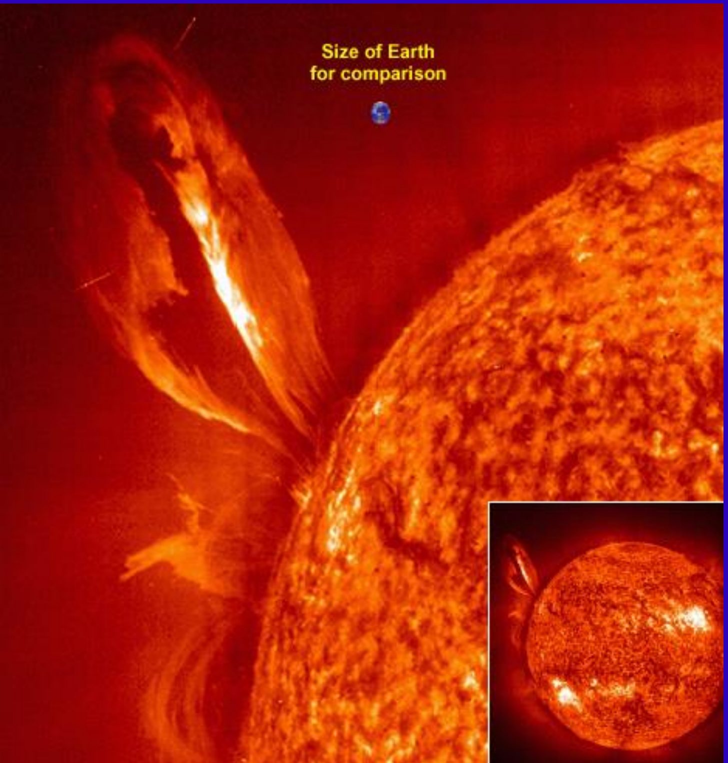
cause moderate to severe sudden ionospheric disturbances

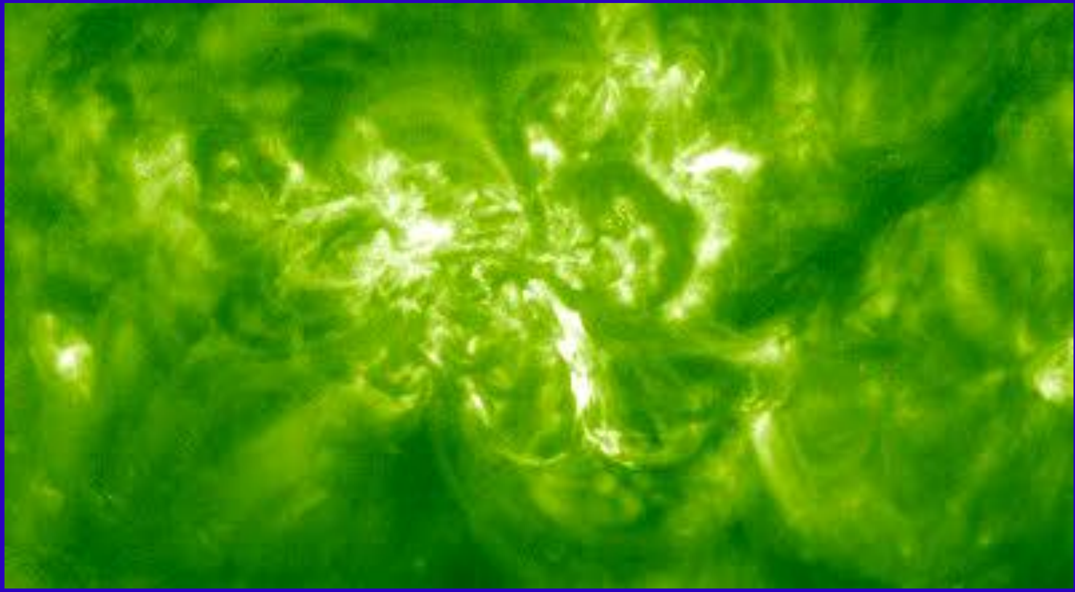
More Frequent M and X-Class Solar Flares

Solar flares accelerate suddenly and without warning from solar active regions

X-class and M-class flares are often associated with fast CMEs

95% of solar flares occur when the solar flux index is 90 or greater
during the seven years of greatest activity during each solar cycle





Huge X20-class solar flare
28 October 2003

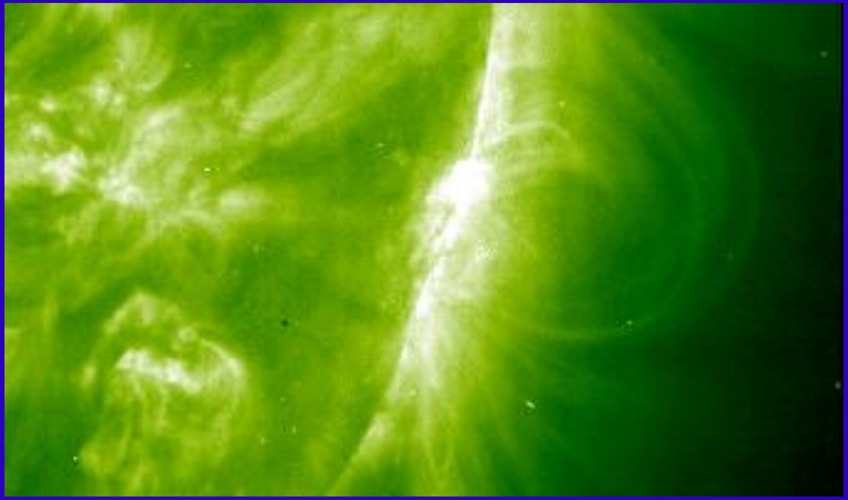
M and X-Class Solar Flares

X-class flares severely impact HF ionospheric propagation

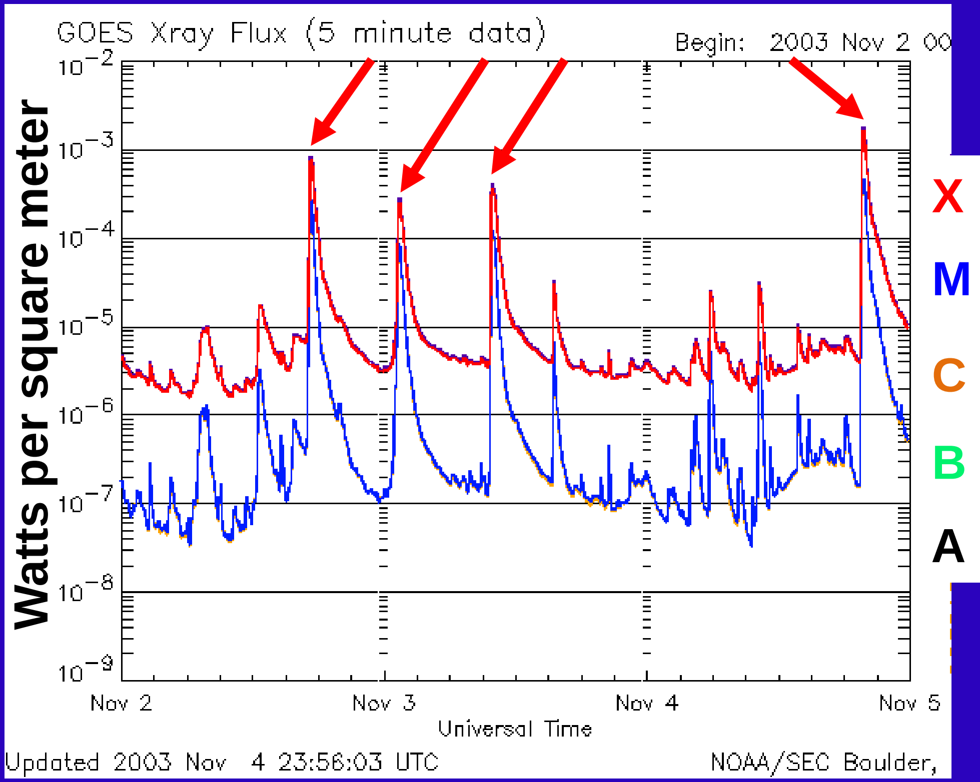
X10-Class – extreme flares produce long duration planet-wide radio blackouts

X-Class – major flares produce planet-wide radio blackouts and severe geomagnetic storms during the most active four years near solar maximum.

M-Class – medium flares produce polar region radio blackouts and degrade HF ionospheric propagation mostly at high latitudes during the more active seven years of the solar cycle



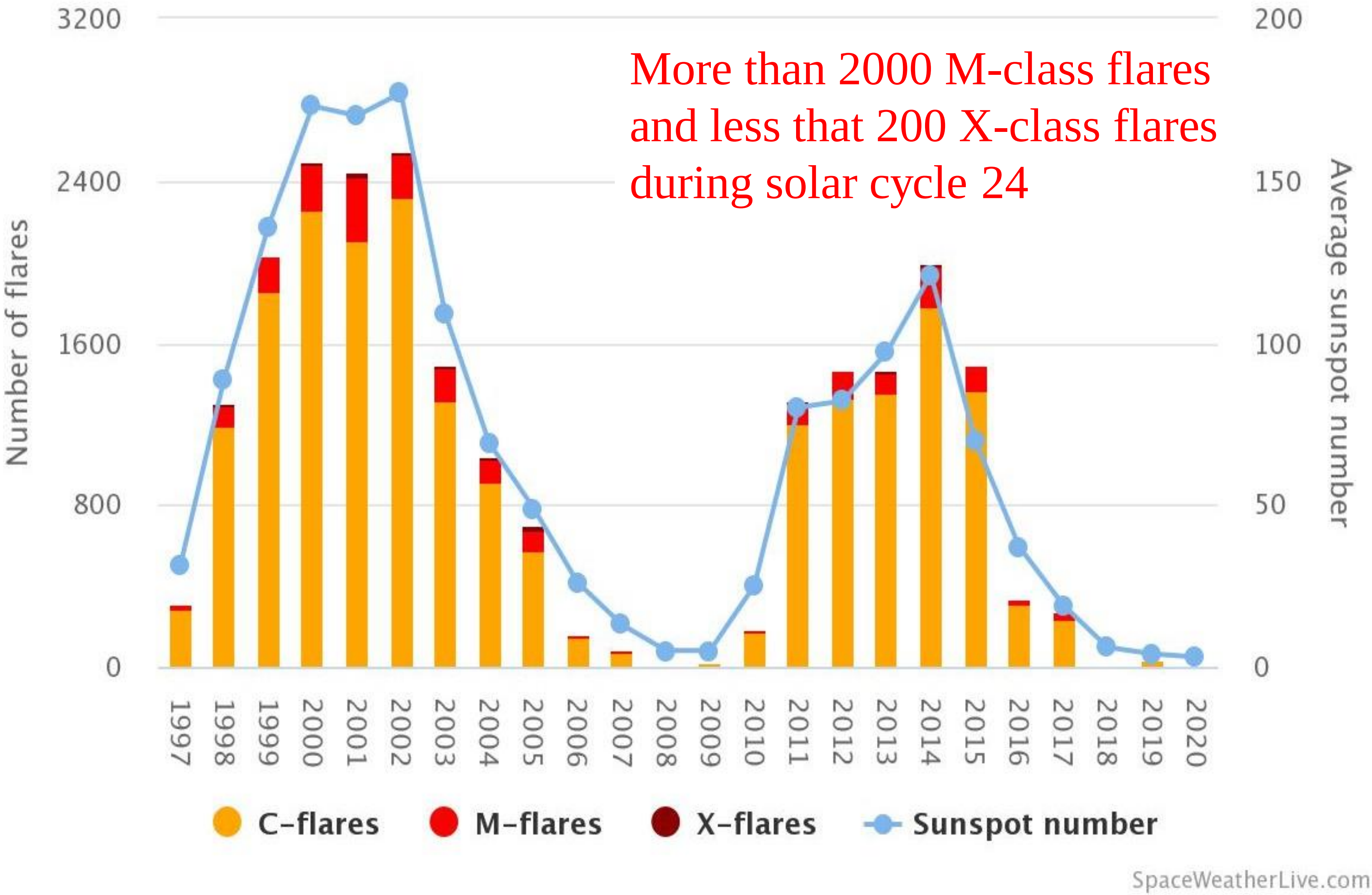
Y2.8 flare -- the largest ever recorded erupts on November 4, 2003



Four X-class and five M-class flares 2-5 November 2003

Flares are classified on a logarithmic scale according to their x-ray brightness

Varying Frequency of C, M and X-Class Solar Flares During Solar Cycle 23 and 24



Daytime HF Ionosphere Propagation Blackouts Caused by Sudden Ionospheric Disturbances

Sudden ionospheric disturbances occur *only* during daylight hours

Hard x-ray radiation from Y-class solar flares increases the ionization of the D region by one or two orders of magnitude, causing dramatically increased or near total absorption of HF ionospheric propagation up to 30 MHz

Disrupts HF propagation at lower frequencies for a longer duration and with significantly more absorption than at higher frequencies

HF ionospheric propagation gradually returns to near pre-SID levels after an hour or two. Reduced absorption begins at higher frequencies

X-Class Solar Flares
Cause the most severe and long lasting SIDs

X20-class **fewer than one event per solar cycle lasting several hours**
Completely black out HF propagation on the entire sunlit side of the Earth
-- occur only during the most active 2-3 years near solar maximum --

X10-class **8 events (8 days) per solar cycle lasting one or two hours**
Blacked out HF propagation on most of the sunlit side of the Earth
-- X10 and X20 class solar flares also cause polar cap absorption --

X1-class **175 events (140 days) per solar cycle lasting about an hour**
Briefly blacked out high latitude HF propagation on the sunlit side of the Earth

M5-Class **350 events (300 days) per cycle lasting tens of minutes**
Possibly blacked out high latitude HF propagation on the sunlit side of the Earth

M1-class **2000 events (950 days) per solar cycle lasting a few minutes**
Briefly degraded high latitude HF propagation on the sunlit side of the Earth

Nowcasting using the Reverse Beacon Network
80 Meters European CQ heard in North America 0500Z