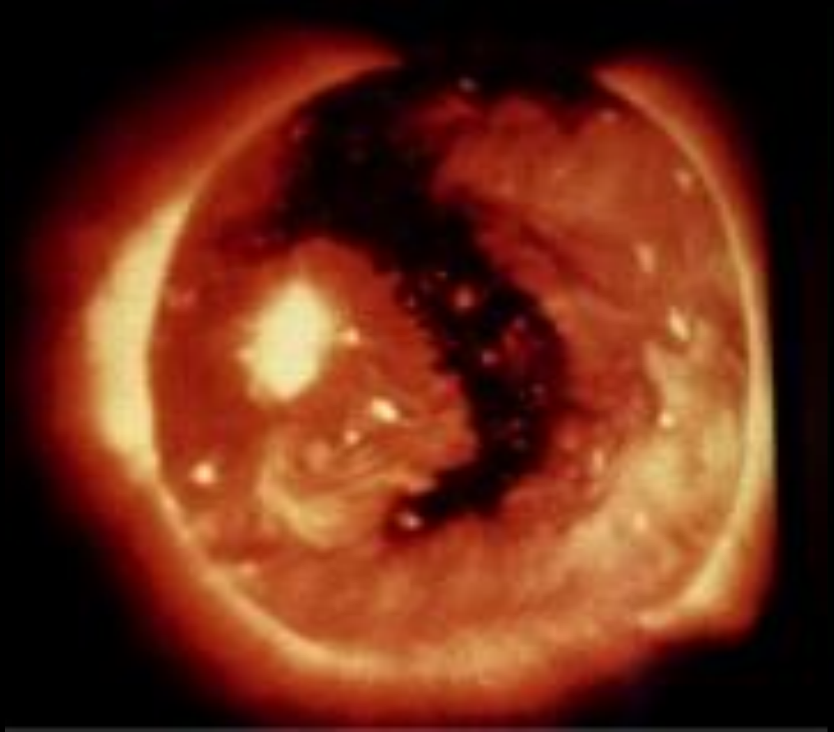
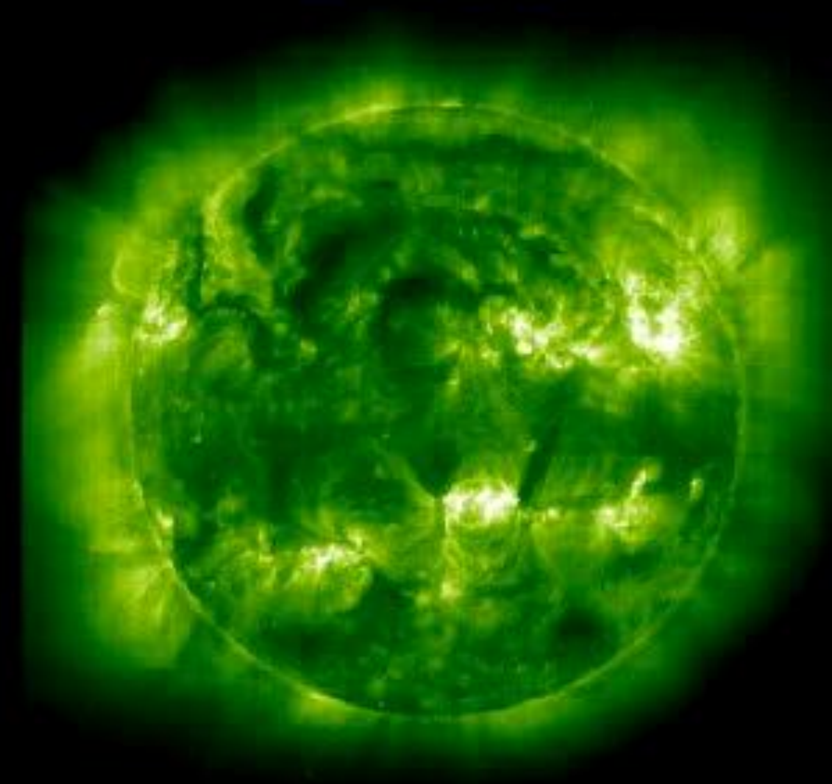
High Frequency Propagation
During the Rising Phase of Solar Cycle 25

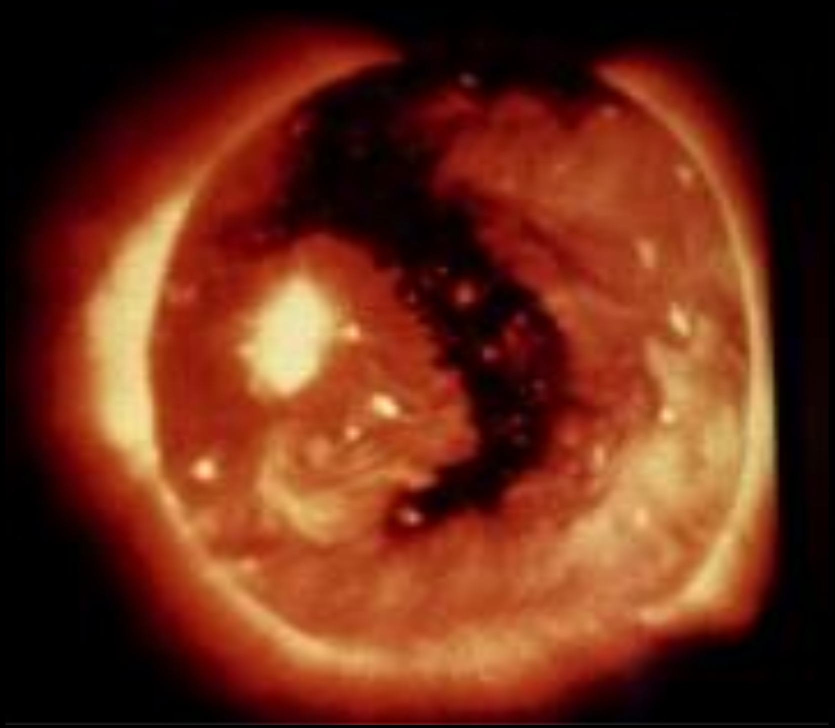




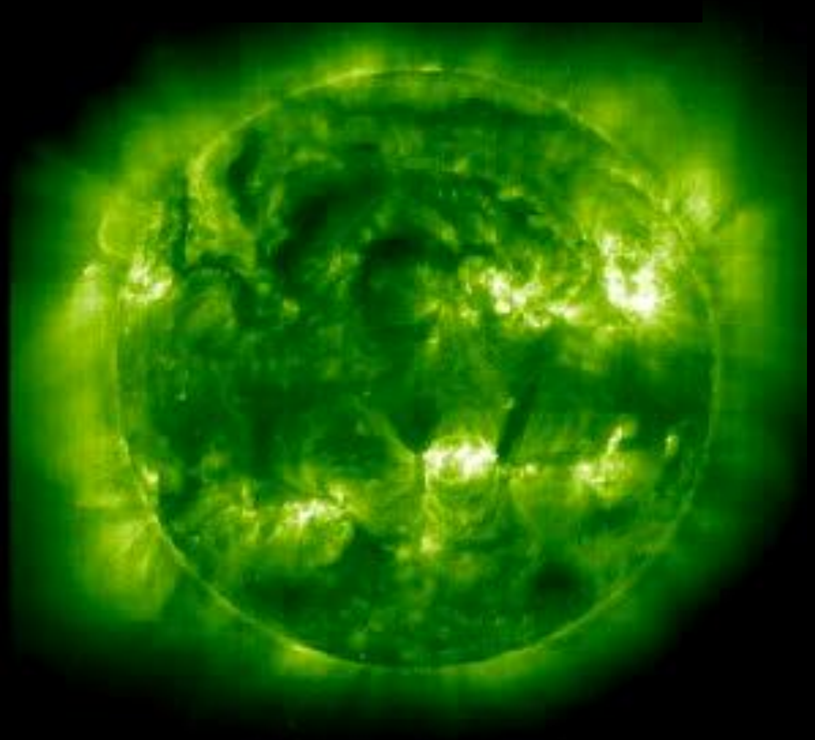
Frank Donovan
W3LPL
donovanf@erols.com

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

Solar Minimum

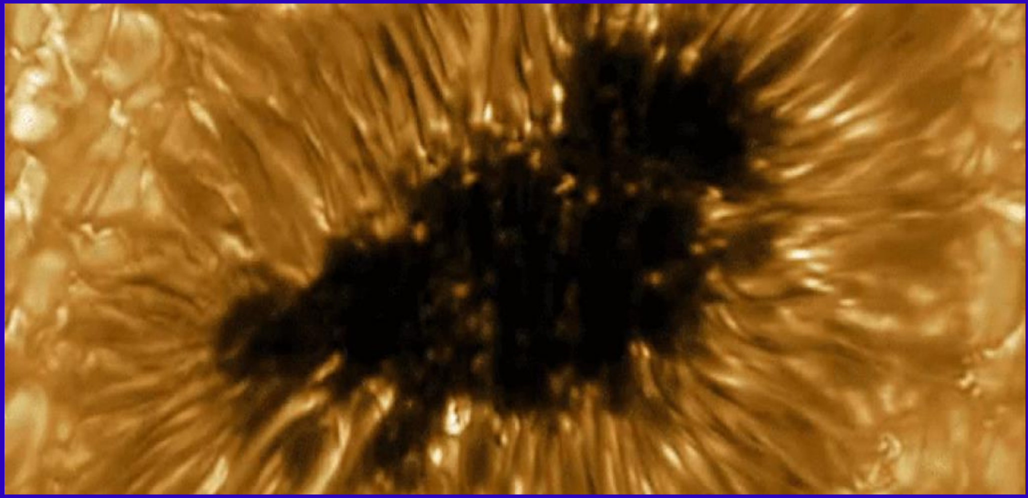


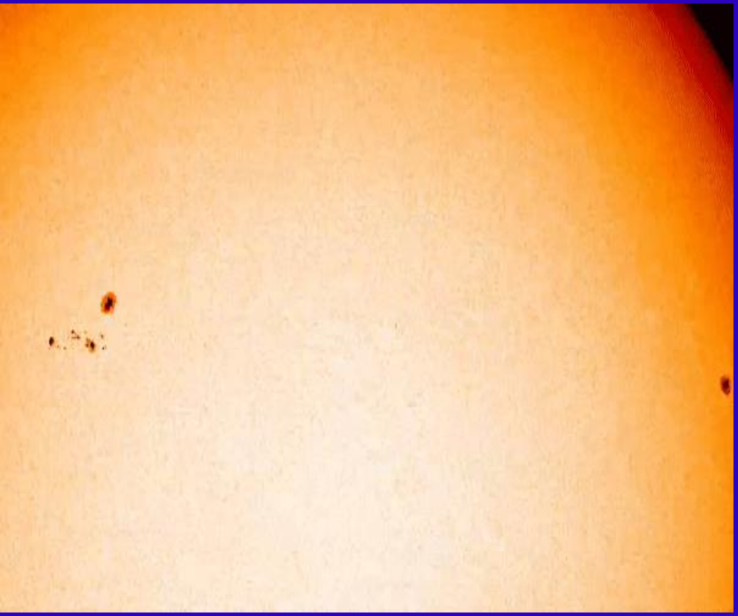
Solar Maximum



Solar maximum improves propagation on the higher bands but brings much more frequent geomagnetically disturbed days

More Frequent, More Energetic Sunspots and their active regions

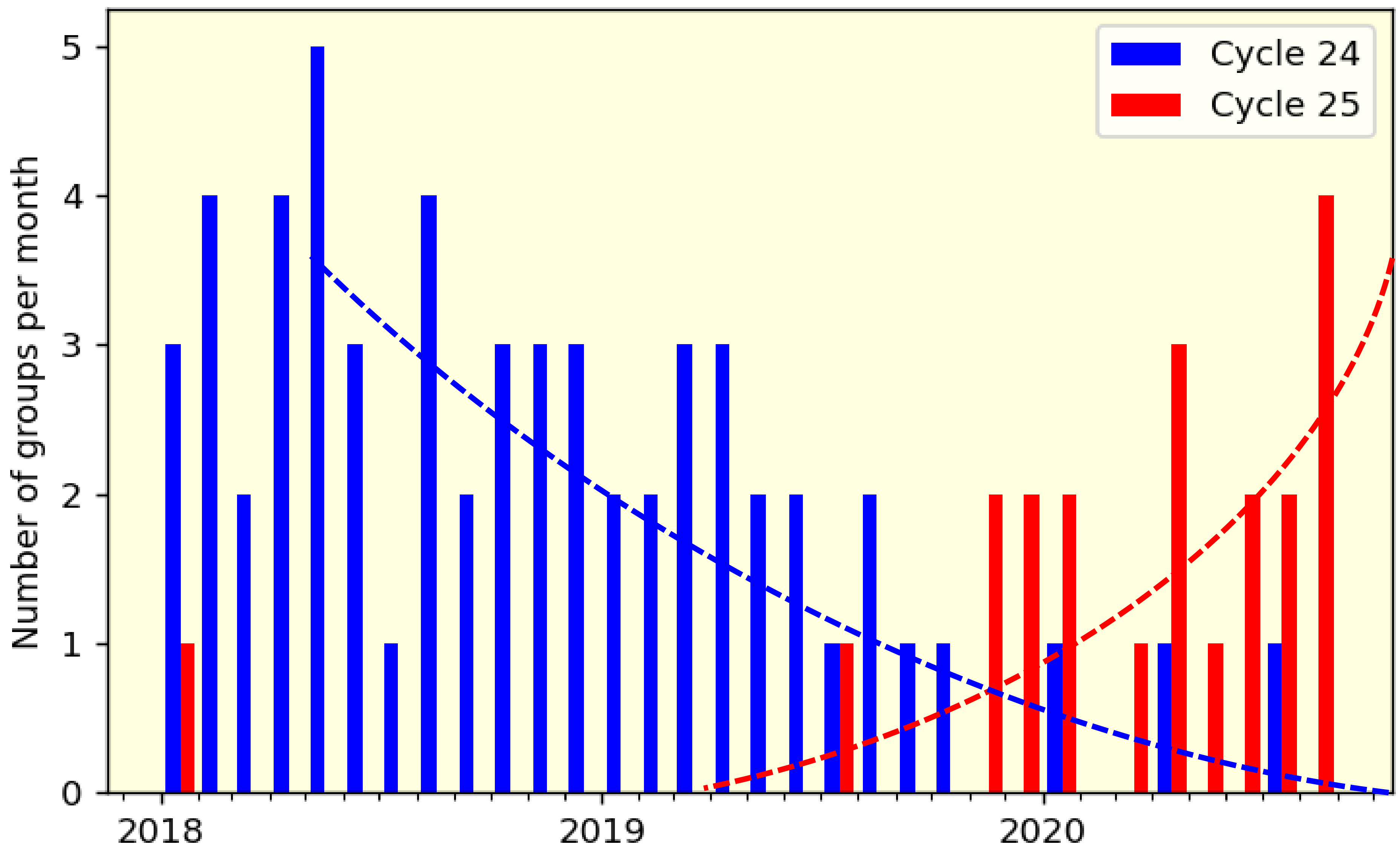




Active regions radiate:

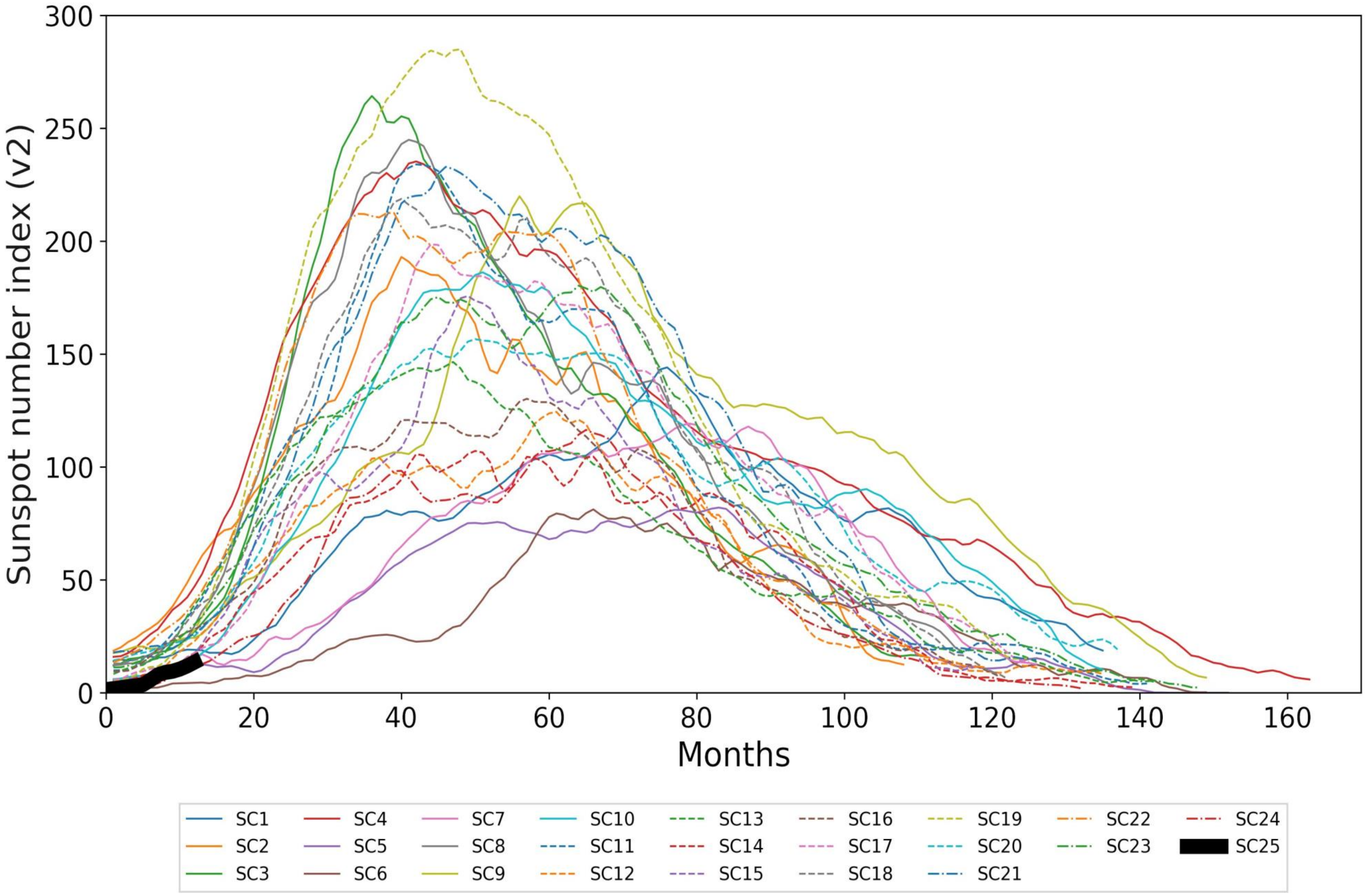
- ionizing ultra violet light
- highly energetic plasma from fast CMEs
- highly energetic hard x-rays from solar flares

Slowly Increasing Solar Cycle 25 Sunspot Activity
the last solar cycle 24 sunspot was on July 4, 2020



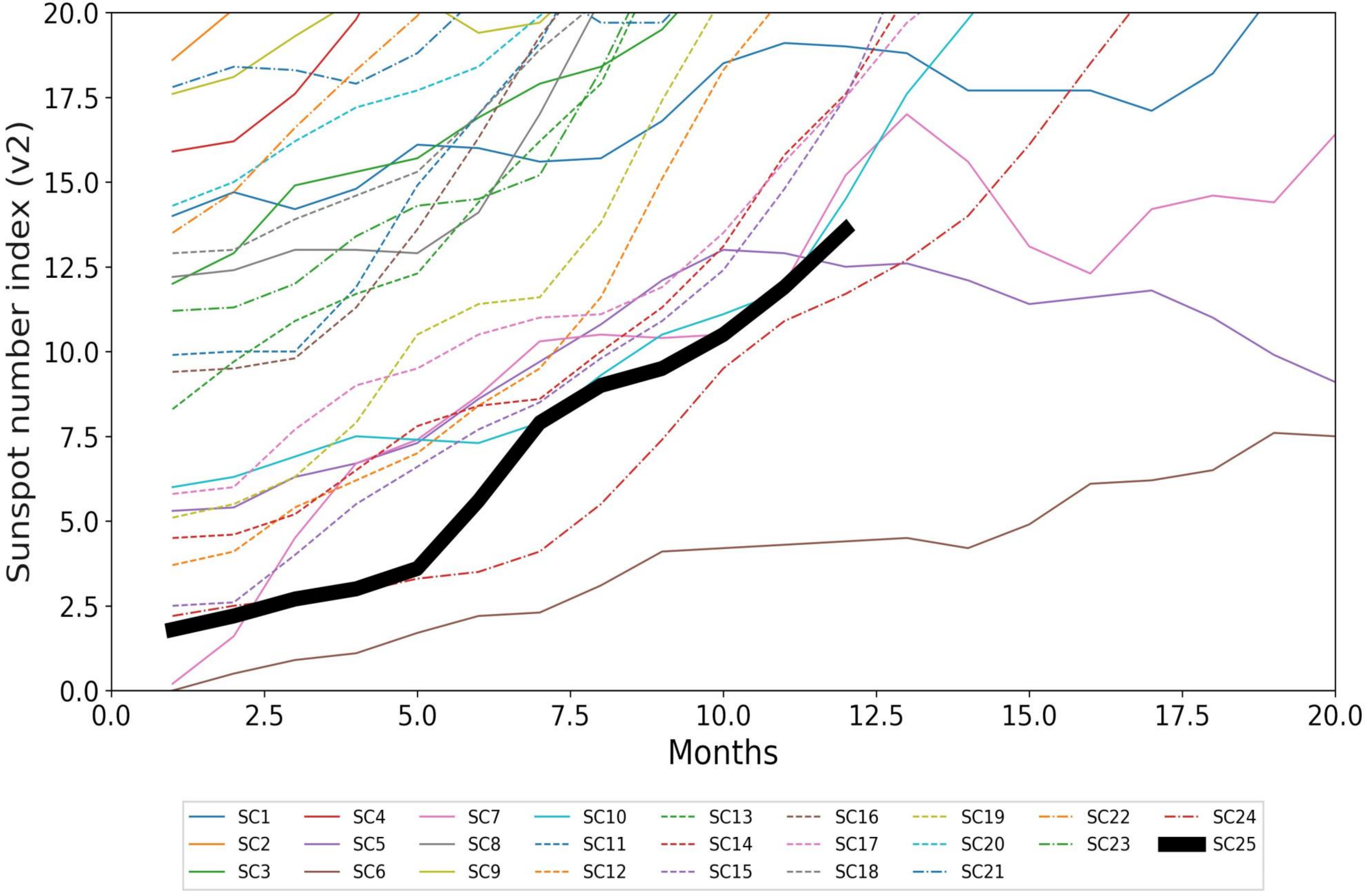
Slowly Increasing Solar Cycle 25 Sunspot Activity

Progress of solar cycle 25



Slowly Increasing Solar Cycle 25 Sunspot Activity

Progress of solar cycle 25



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
- 17, 15, 12 and 10 meters during daylight and evening hours
- 30 and 20 meters during the night

Higher sunspot numbers also increase the frequency and intensity of:

- strong to severe geomagnetic storms
- sudden ionospheric disturbances

F1 and F2 Region Variability

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

F2 ionization is greatest during the day

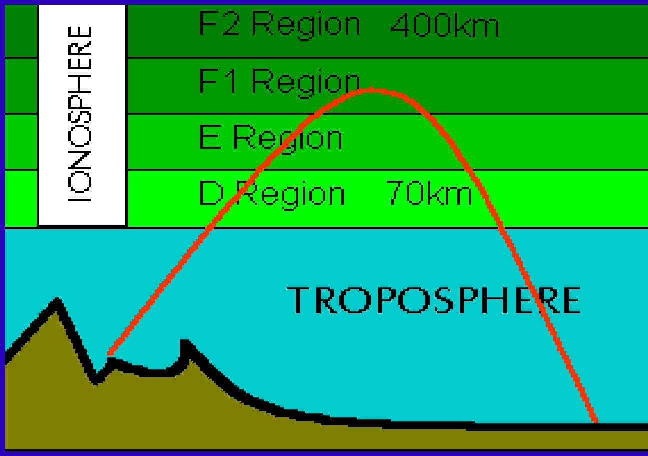
The F2 ionization is significantly weaker at night causing significantly reduced MUFs especially during the winter and during solar minimum

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

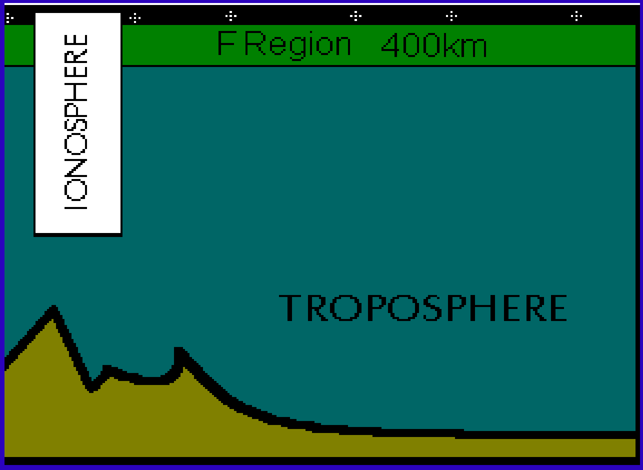
- rising, maximum, declining, minimum

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

The F1 and F2 regions merge at night

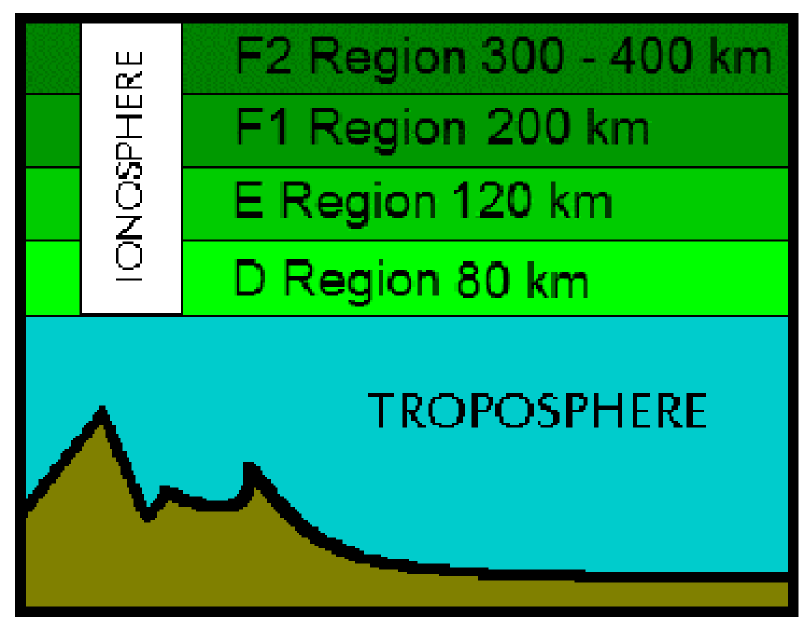


Day



Night

Summer Night Time F2 Propagation

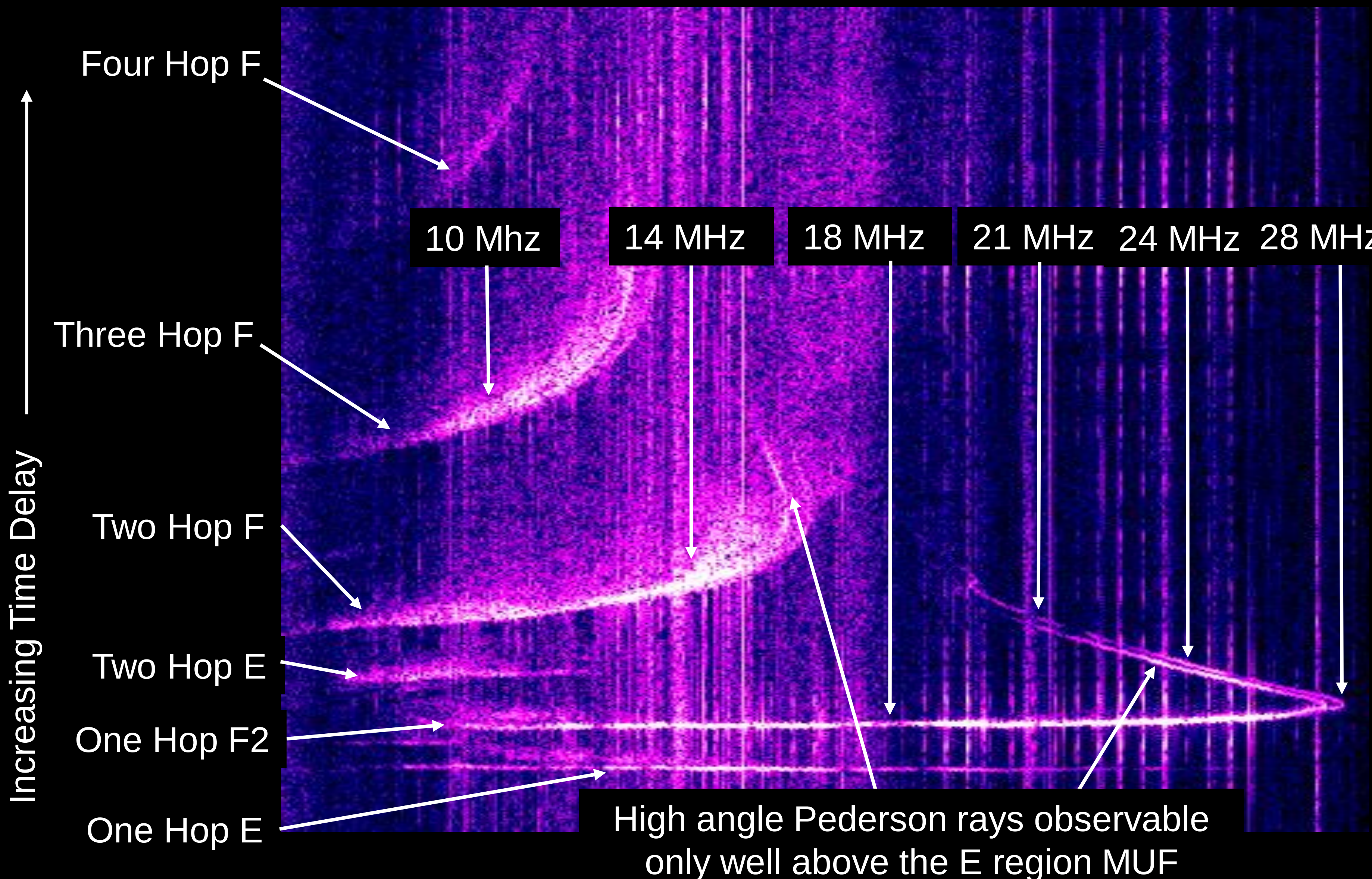


E region and F1 region blanketing of the F2 region ends several hours before sunset

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

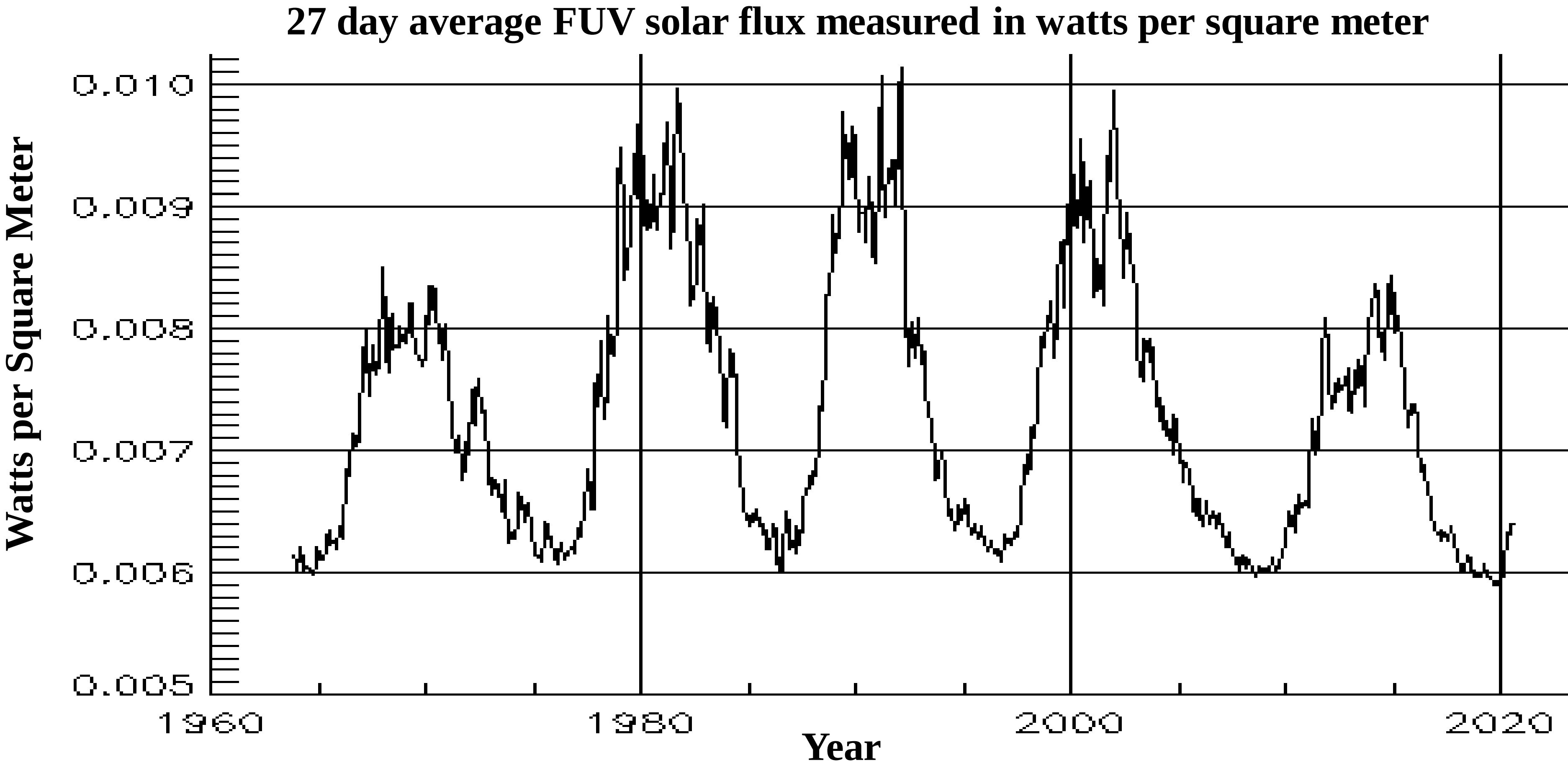
The night time F region is less densely ionized and has lower MUFs than the daytime F2 region

Multi-Path Ionospheric Propagation as detected in an unprocessed *oblique* ionogram

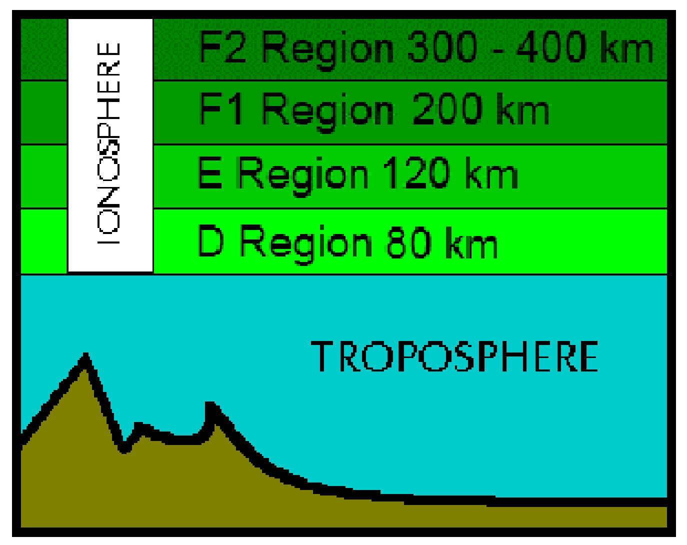


Increased Mid-Latitude D Region Absorption
caused by 30-50% increase in far ultraviolet radiation

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



More Severe E Region Blanketing of low angle long distance F region propagation



During the years near solar maximum

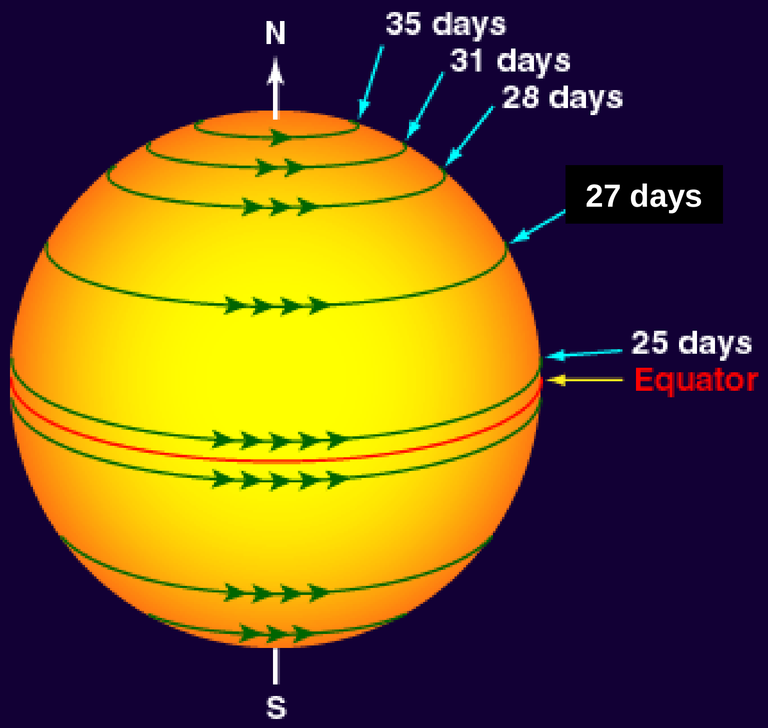
The E region blankets low angle
40 meter long distance F region
Propagation until late afternoon

The E region blankets low angle
80 meter long distance F region propagation
until sunset -- and sometimes much later –

Residual night time E region ionization absorbs and blankets
low angle 160 meter F region propagation throughout the
year

27 Day Recurrence of Sunspots and Geomagnetic Disturbances

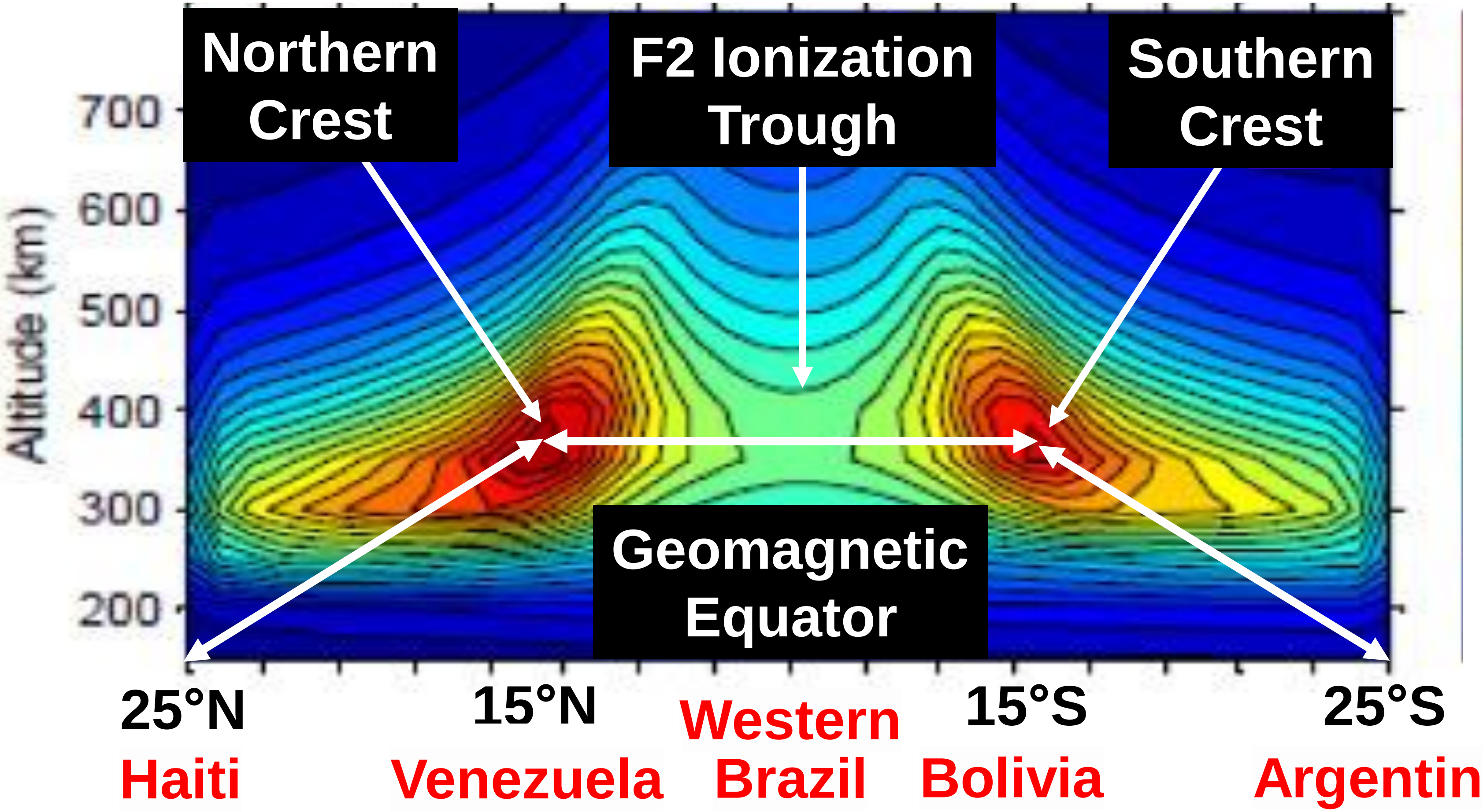
27 day recurrence of solar events becomes more apparent as sunspots become persistent features on the visible solar disk



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

6 Meter Trans-Equatorial Propagation (TEP) via the F2 Equatorial Ionization Anomaly

MUF enhancing TEP occurs most often during the spring and fall at about 1500-1900 local solar time at the reflection points between mid-latitude locations each about 2000 to 2500 miles north and south of the ***geomagnetic*** equator



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 --

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
-- but not during during the summer --

More reliable, more frequent long path openings

More reliable, more frequent and longer duration night time DX
year round

Degraded Summer Mid-Day 20 Meter DX Propagation
F1 region blanketing of low angle radiation

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

What bands should I use for DX during the next two years of rising sunspot activity?

- Each band has its unique advantages and disadvantages
- The most reliable daytime worldwide DX propagation is on 20 and 17 meters and increasingly 15 meters
- The most reliable nighttime worldwide DX propagation is on 40 meters throughout the year
- 20 meters usually has excellent nighttime worldwide DX propagation during the spring and early summer
- 80 meters provides excellent nighttime worldwide DX propagation from October through April

Long Distance Propagation During the Next Two Years of Rising Sunspot Activity

The 20 meter band almost always supports worldwide DX propagation during daylight hours during every part of the solar cycle

The 40 and 30 meter bands support worldwide DX propagation from mid-late afternoon through shortly after sunrise throughout the year

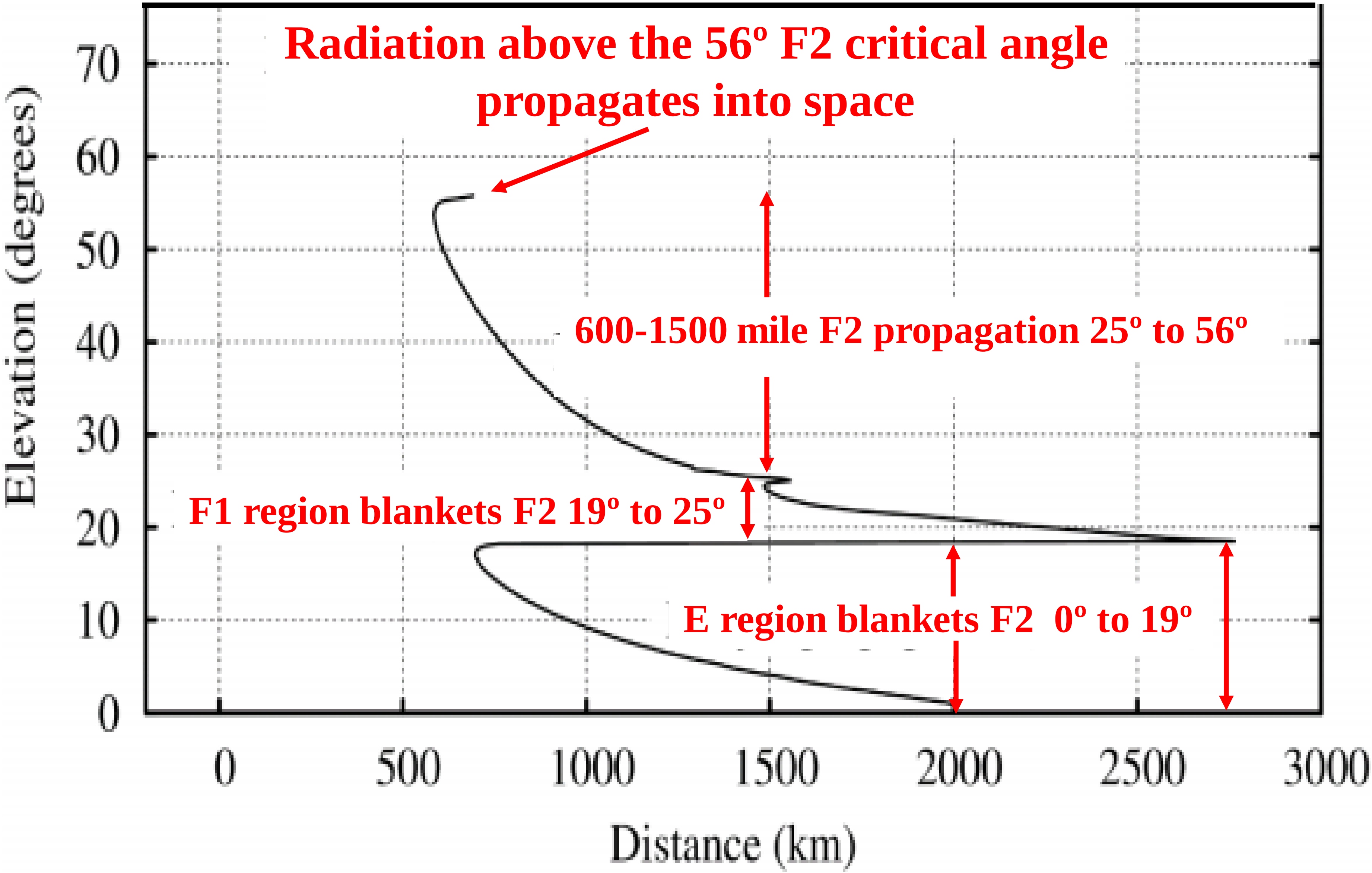
The 160 and 80 meter bands support worldwide DX propagation during night time hours primarily from October through April

17 and 15 meters become much more reliable for DX communications as sunspot activity increases

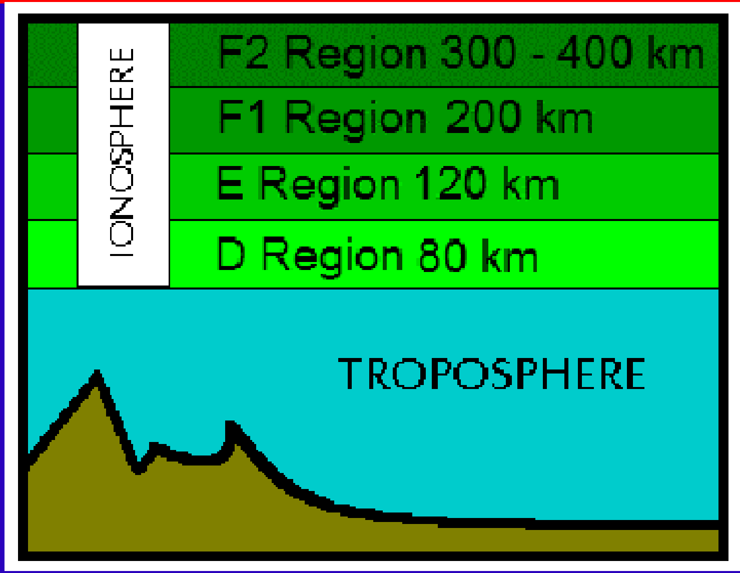
12 and 10 meters become somewhat more reliable for DX communications as sunspot activity increases

E and F1 Region Blanketing of summer daytime 20 meter F2 propagation

20 meters **noon local time** **summer** **low SSN**



The F1 Region 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
- much more frequently at low latitudes

The F1 region significantly degrades 20 meter long distance propagation during summer mid-day hours by blanketing low angle propagation via the F2 region

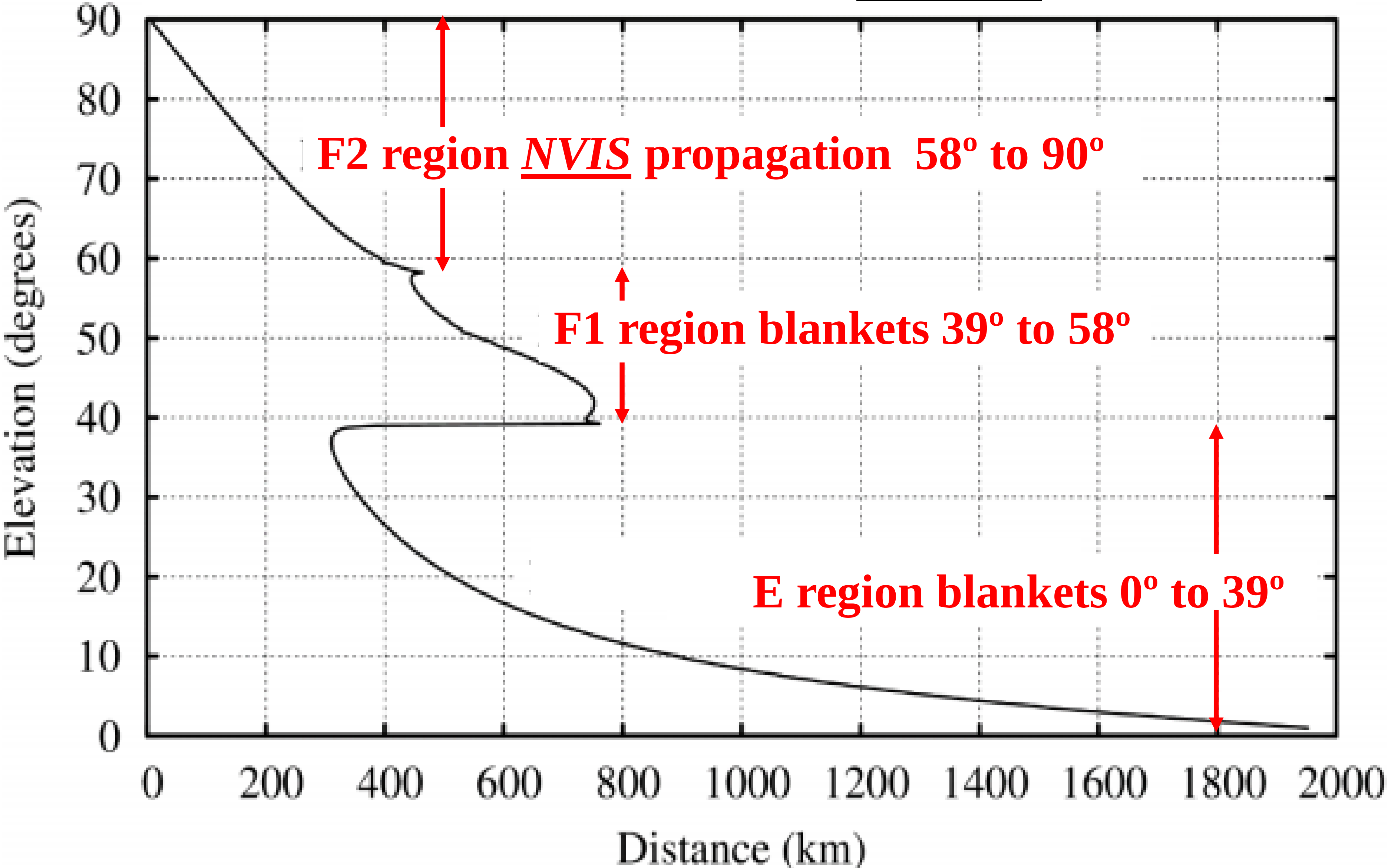
Degraded 40 Meter Propagation

long lasting D region absorption until almost sunset

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

E and F1 Region Blanketing of daytime 40 meter F2 Propagation

40 meters noon local time <u>summer</u> low SSN



Degraded 80 Meter Propagation

increased D region absorption until sunset
residual E region blanketing after sunset

Increased D region absorption until sunset

More rapid increase in D region absorption at sunrise

Increased E region 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 propagation path
control points in the aurora oval

Degraded 160 Meter Propagation

increased D region absorption until sunset

residual E region blanketing after sunset

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

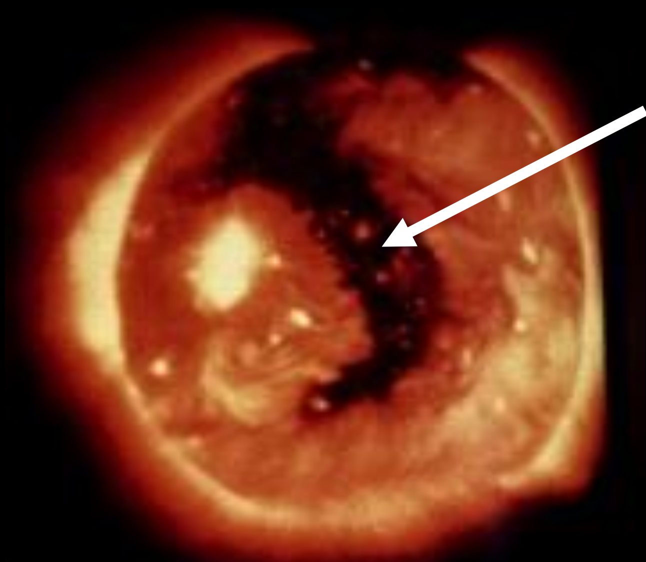
Increased D region absorption in the auroral oval
caused by increased energetic electron precipitation
into the D region after midnight at the propagation path
control points in the aurora oval

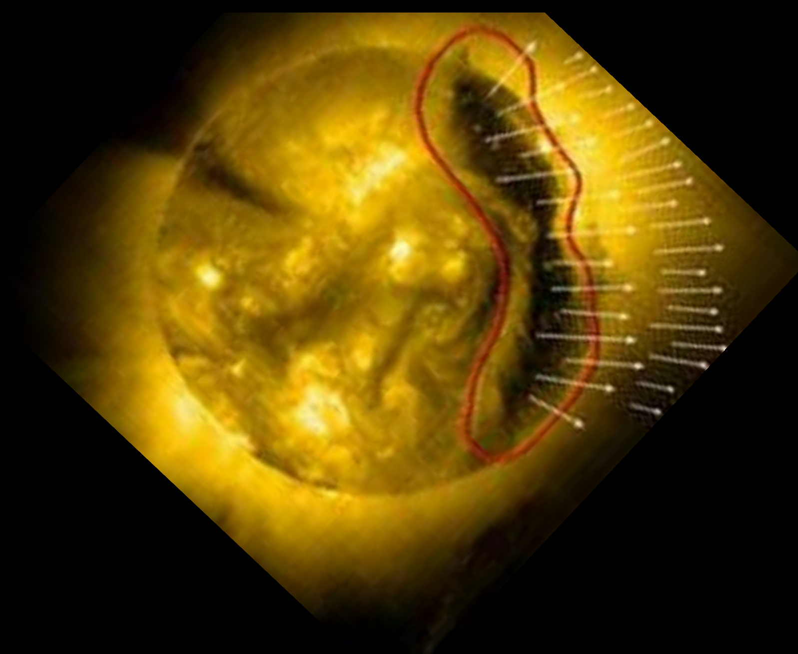
Disturbed Geomagnetic Conditions caused by coronal hole high speed streams

Energetic particles flowing from open magnetic field lines in coronal holes are the primary source of the fast solar wind

The fast solar wind causes unsettled to active geomagnetic disturbances mostly during the declining years of the solar cycle

Disturbed geomagnetic conditions caused by coronal hole high speed streams becomes less frequent during the rising years of the solar cycle and very infrequent near solar maximum



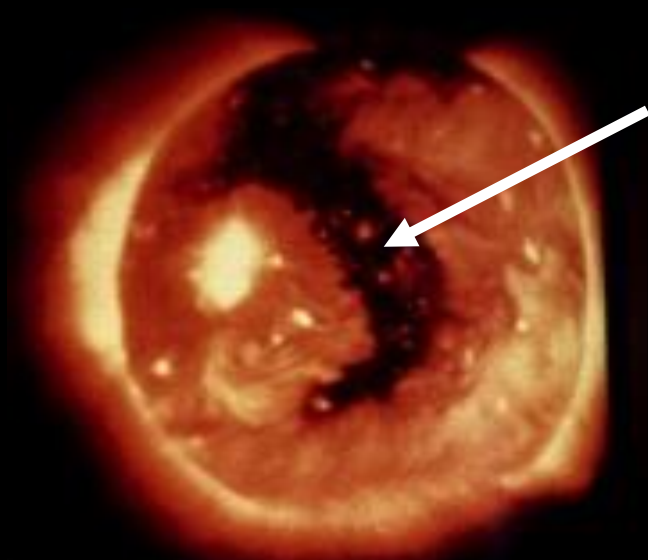


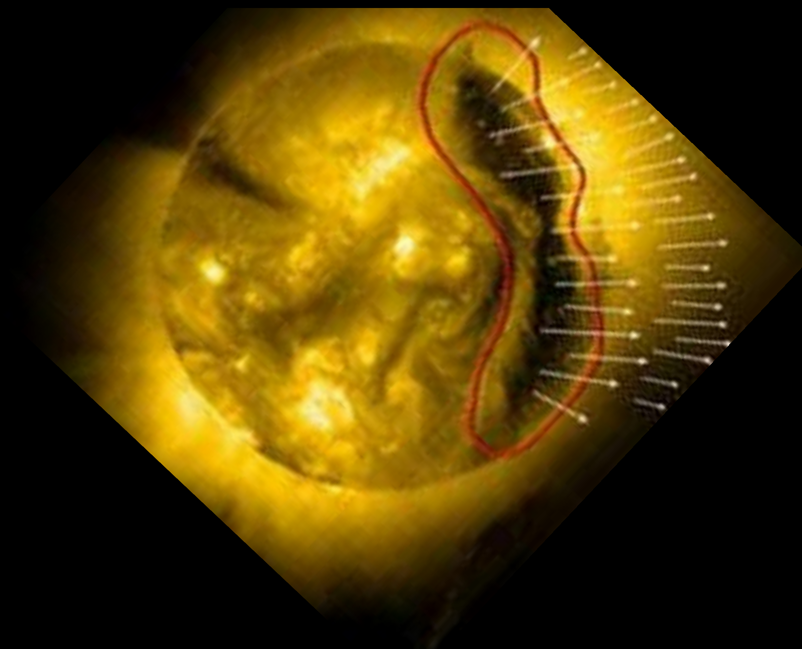
Disturbed Geomagnetic Conditions caused by coronal hole high speed streams

Streams of energetic particles flowing from coronal hole's open magnetic field lines are the primary source of high speed solar wind

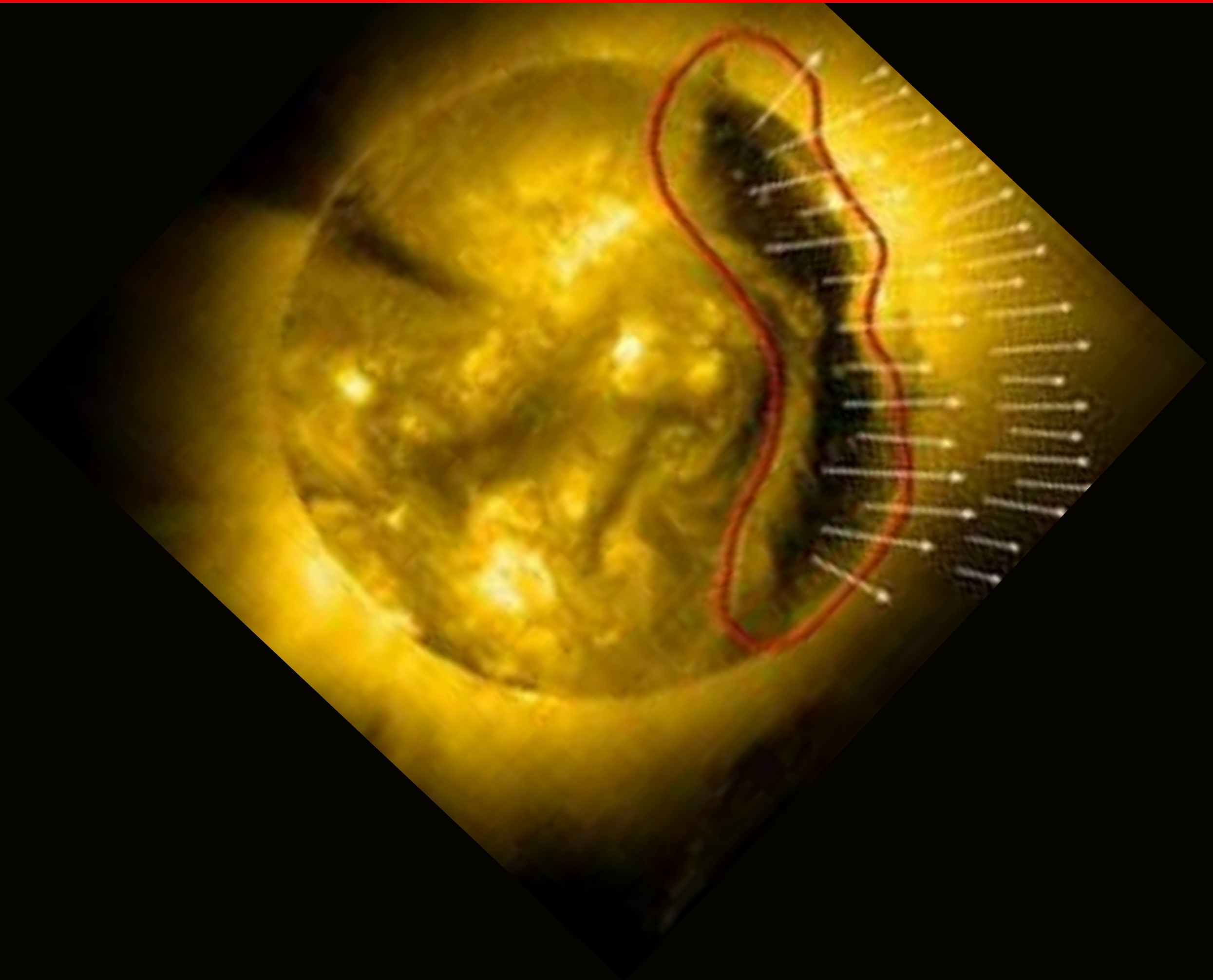
Coronal hole high speed streams cause geomagnetic disturbances and minor storms mostly during the declining years of the solar cycle

Geomagnetic disturbances and minor storms have less impact on propagation during solar maximum because increased ionizing solar radiation compensates for minor propagation degradation



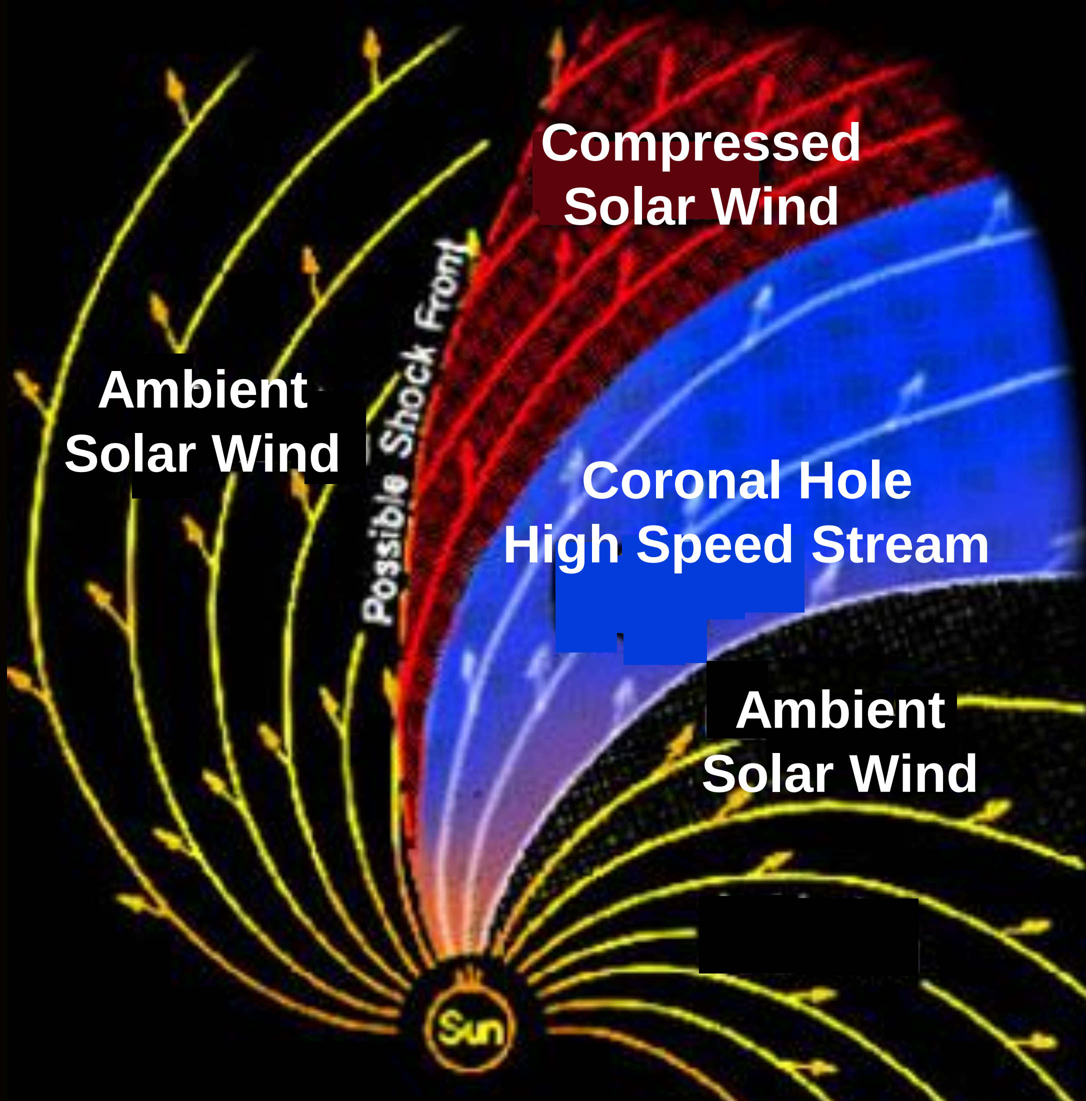


Less frequent and shorter duration
geomagnetic disturbances and minor storms
<u>caused by coronal hole high speed streams</u>
during the rising and maximum phases of the solar cycle



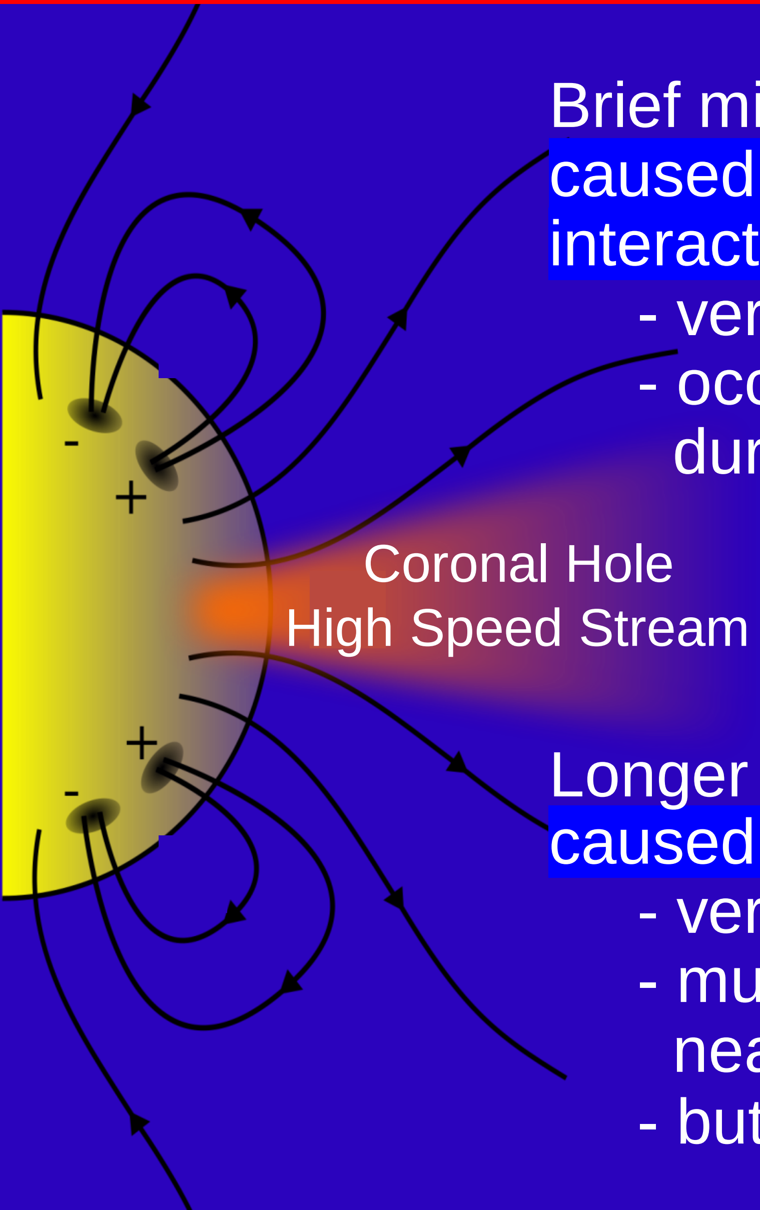
Co-Rotating Interaction Region

The ambient solar wind is greatly enhanced when a coronal hole high speed stream collides with it



Minor Geomagnetic Storms

cause much less propagation degradation near solar maximum



Brief minor geomagnetic storms
caused by coronal hole high speed stream interactions with the slow solar wind

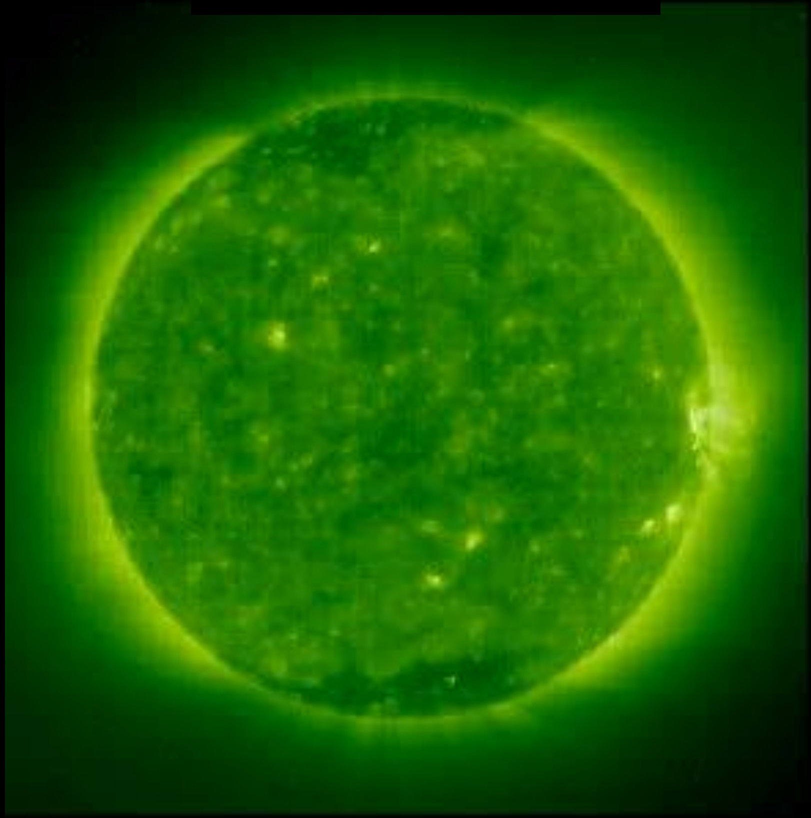
- very frequent near solar minimum
- occur about half as frequently during the years near solar maximum

Longer duration minor geomagnetic storms
caused by fast coronal mass ejections

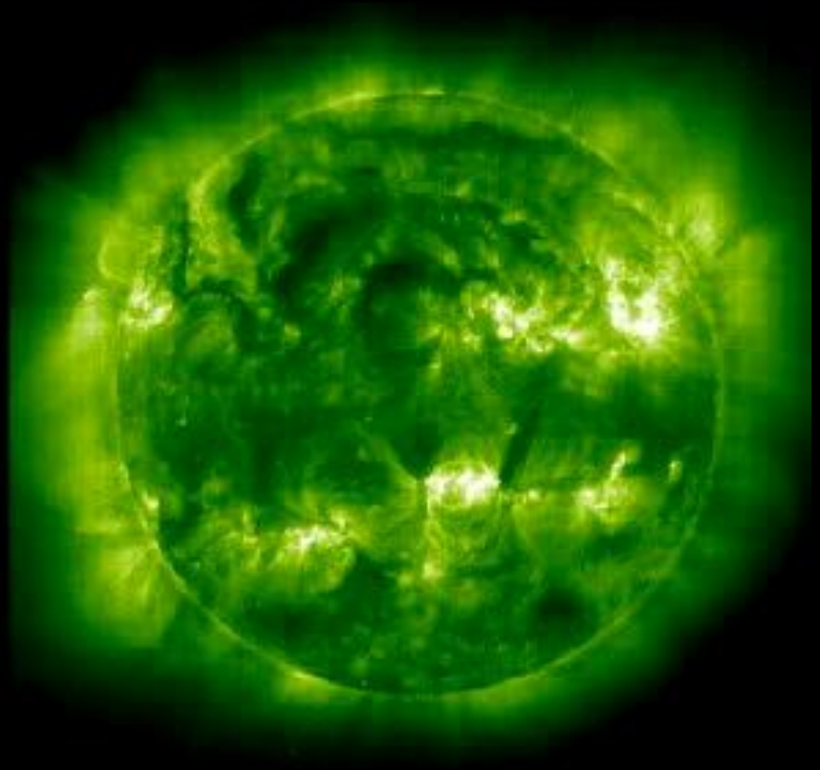
- very infrequent near solar minimum
- much more frequent during the years near solar maximum
- but have little affect on HF propagation

Frequent Fast Coronal Mass Ejections During the rising years of solar cycle 25

Solar Minimum



Solar Maximum

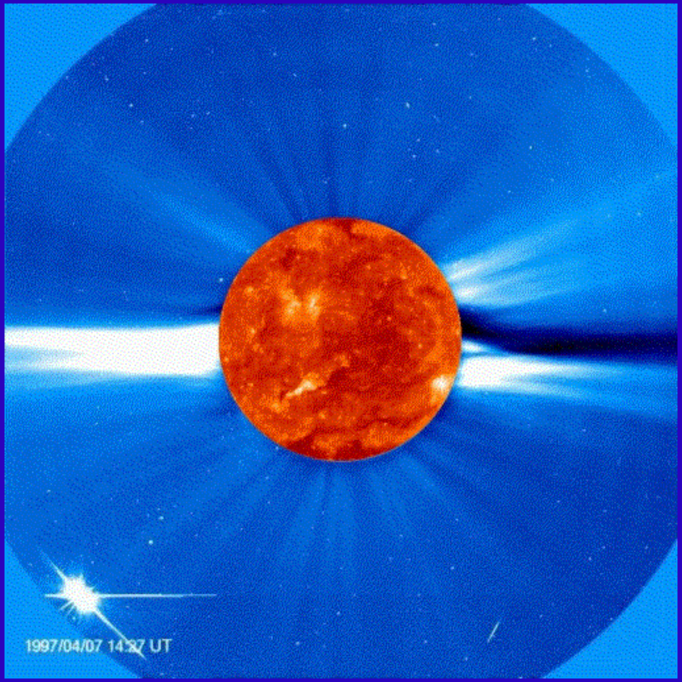


cause more frequent, longer lasting
<u>moderate and severe</u> geomagnetic storms

Fast Coronal Mass Ejections (CMEs)

the dominant cause
of strong to severe geomagnetic storms

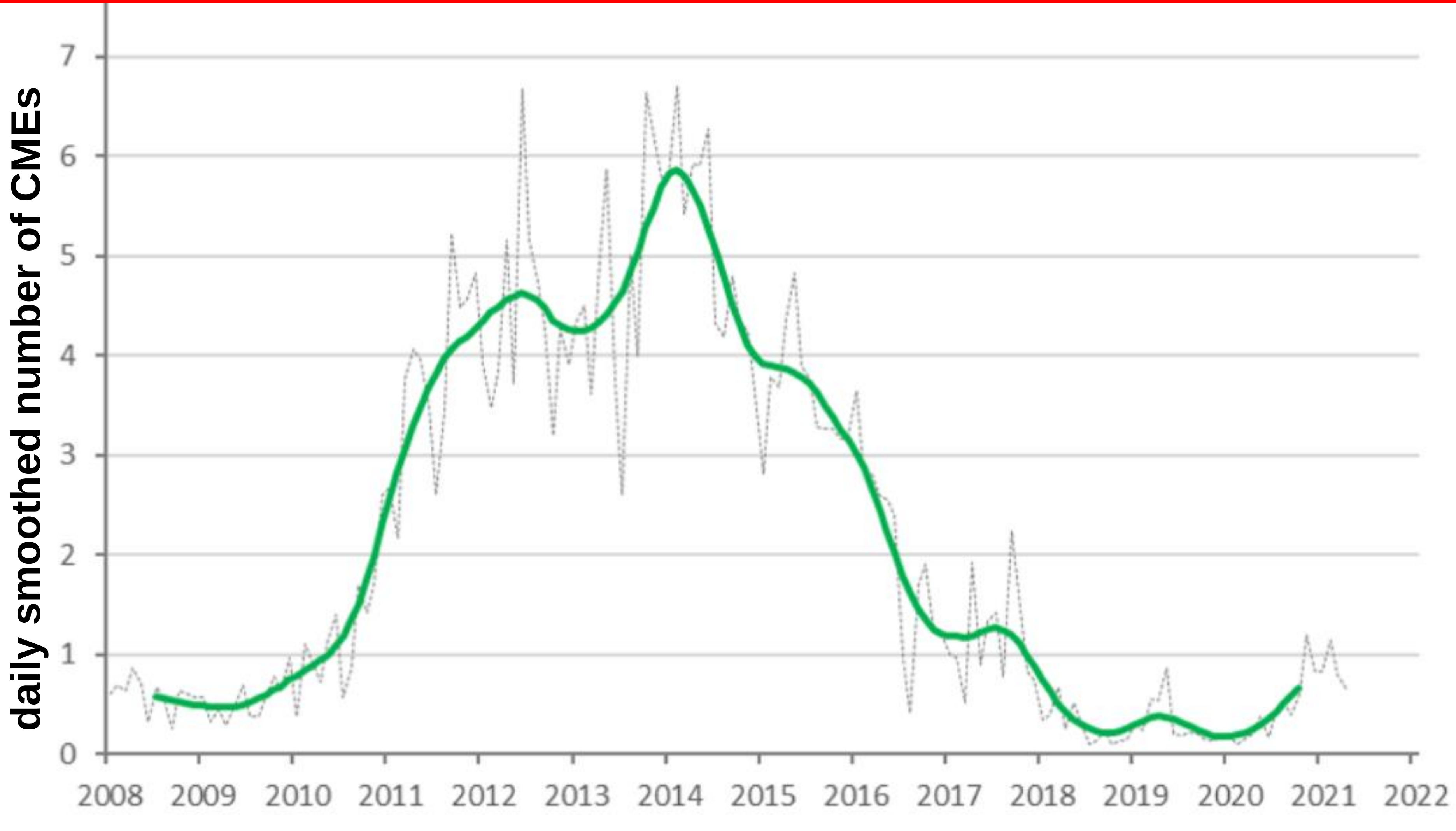
Fast CMEs from solar active regions
are the dominant cause of moderate
to severe propagation disturbances



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

Coronal Mass Ejections (CMEs)

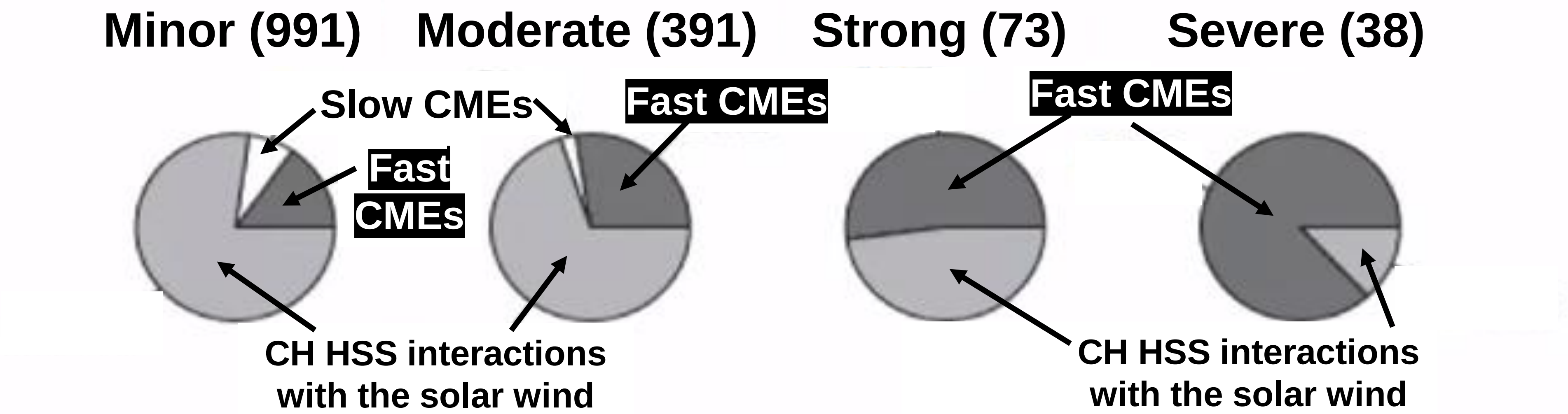
the dominant cause
of strong to severe geomagnetic storms



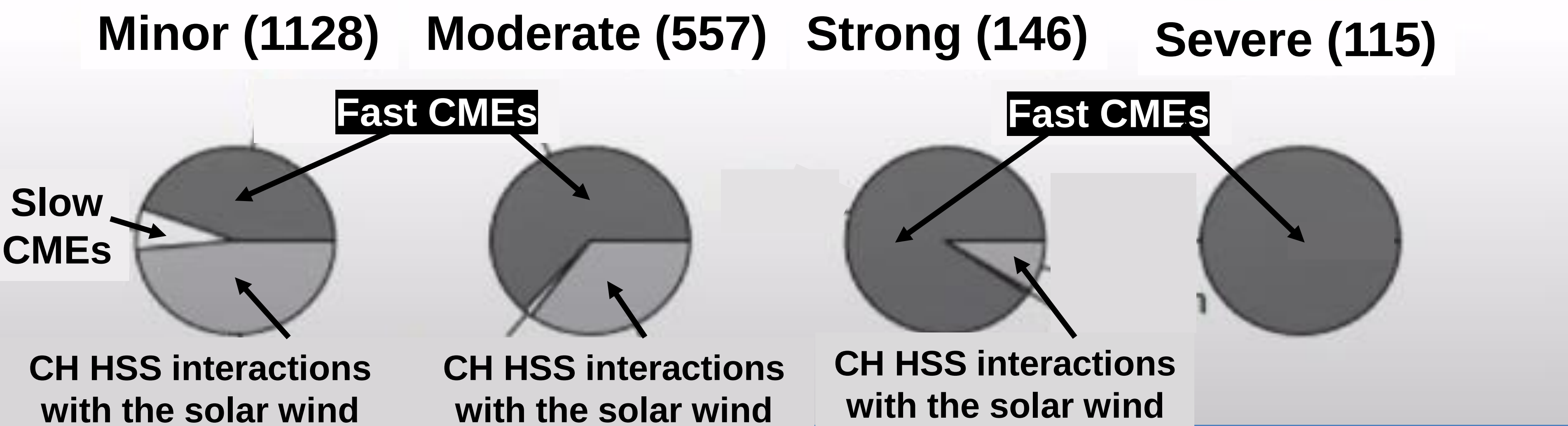
Fast Coronal Mass Ejections (CMEs)

Dominant cause of strong to severe geomagnetic storms

Coronal hole high speed streams cause most storms near solar minimum

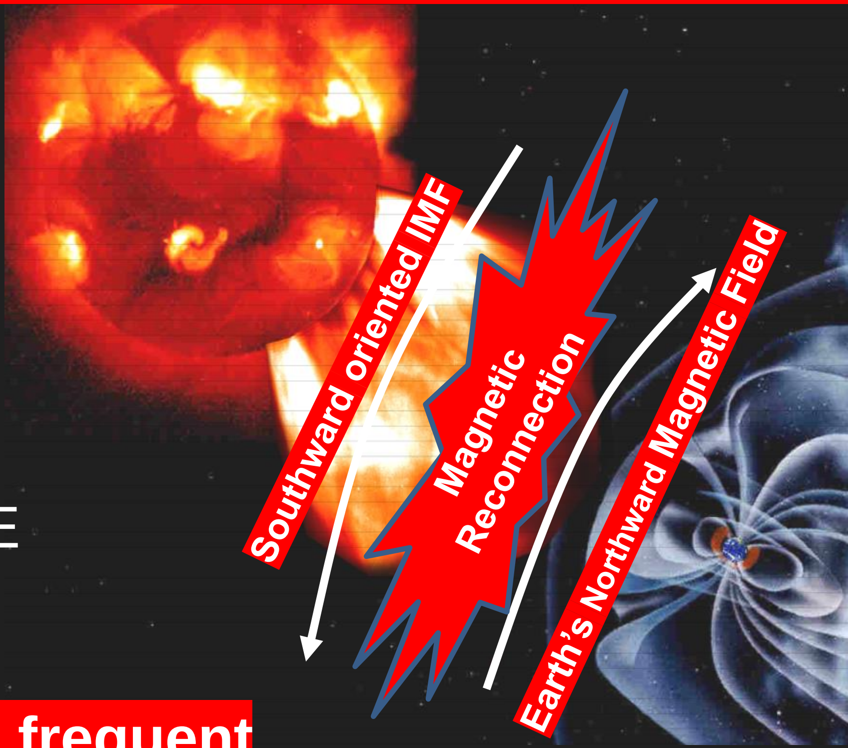


Fast CMEs cause most storms of all sizes near solar maximum



Strong to Severe Geomagnetic Storms
Always caused by persistent southward IMF orientation

Persistent Southward Oriented Interplanetary Magnetic Field (IMF)
causes strong to severe geomagnetic storms when it persists in a southward orientation 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

Geomagnetic Indices - the Planetary Kp Index

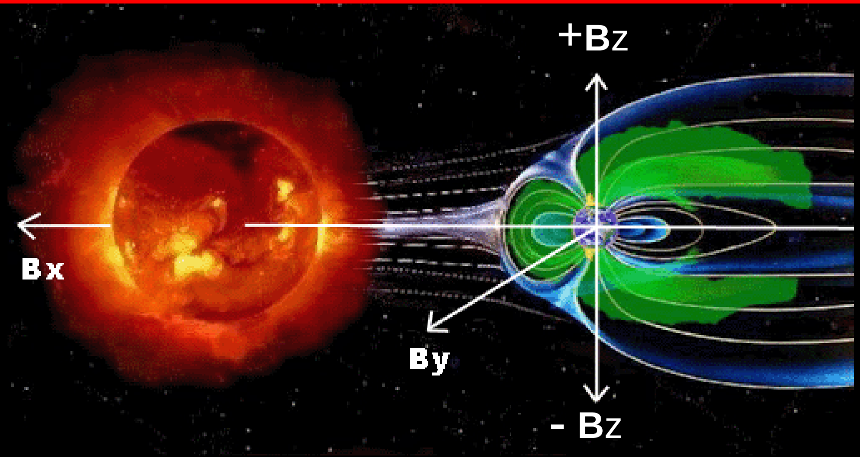
The Kp planetary index of geomagnetic activity is computed every three hours from 13 mid-latitude observatories around the Earth

Kp Index (quasi-logarithmic scale)	Geomagnetic Condition
9	Extremely Severe Storm
8	Very Severe Storm
7	Severe Storm
6	Major Storm
5	Minor Storm
4	Active
3	Unsettled
2	Quiet
1	Very Quiet
0	Inactive

HF propagation is most reliable when Kp is 3 or less

160 and 80 meters are often enhanced when Kp is 2 or less
or during the 12-24 hours *before* the Kp is greater than 5

Persistent 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 often causes 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

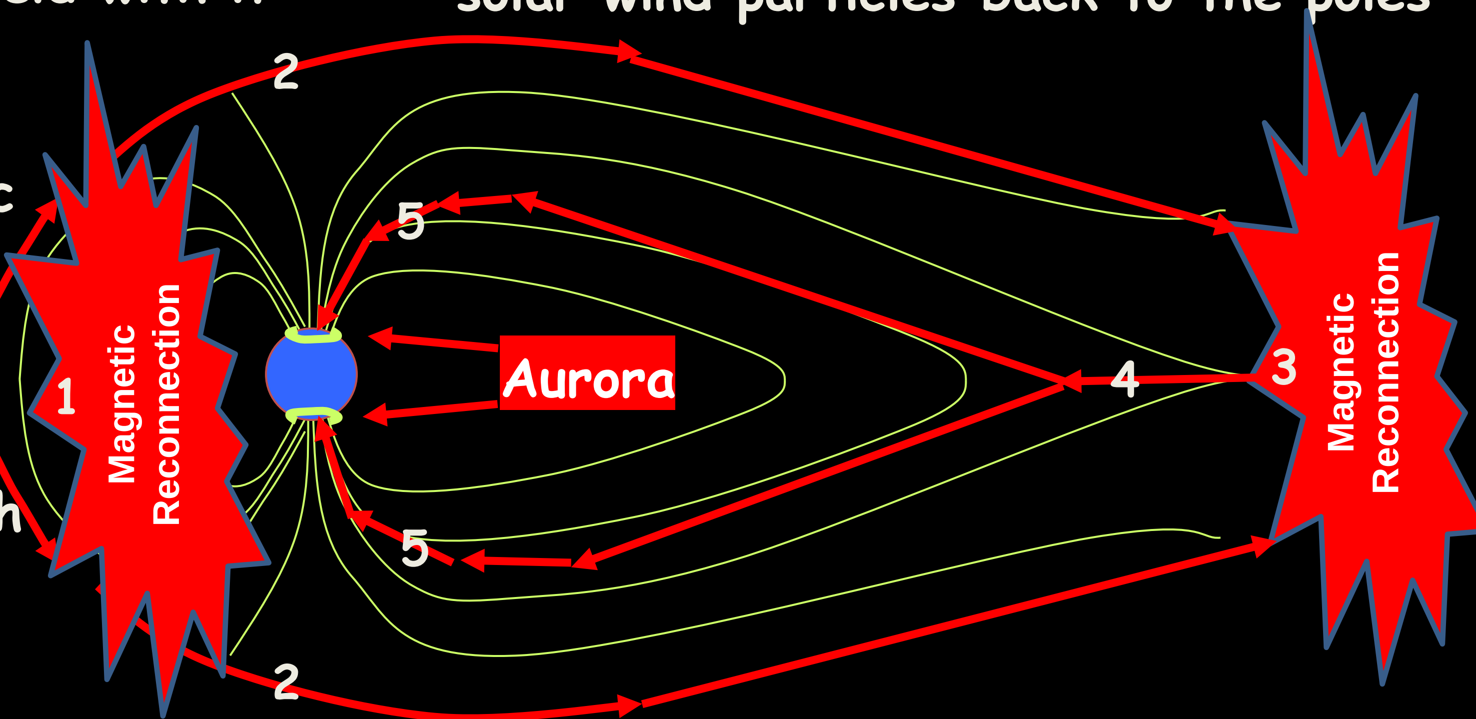
CMEs and Magnetic Reconnection

2. The solar wind is deflected along the magnetosphere and it drags Earth's powerful magnetic field with it

3. Earth's opposite polarity magnetic field lines reconnect at the magnetotail

4. Magnetic reconnection accelerates solar wind particles back to the poles

1. When a CME's magnetic field is oriented southward it magnetically reconnects with Earth's north oriented magnetic field



5. Accelerated particles follow field lines to the Earth's polar regions causing geomagnetic substorms and intensified aurora

Geomagnetic Storm Propagation Impacts

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

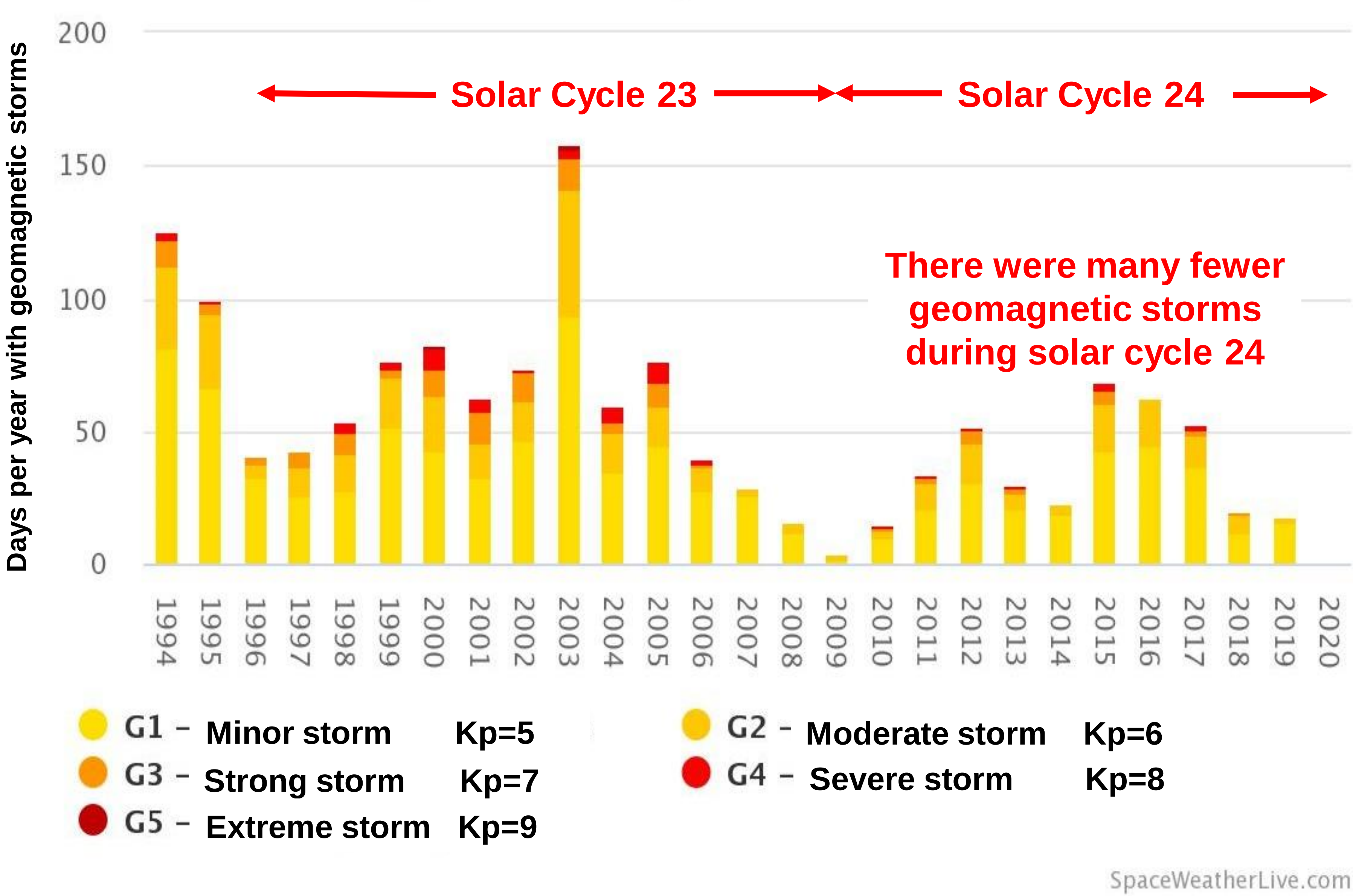
Kp=6 **about 600 events (360 days) per solar cycle**

Unstable HF ionospheric propagation at high latitudes for many hours

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

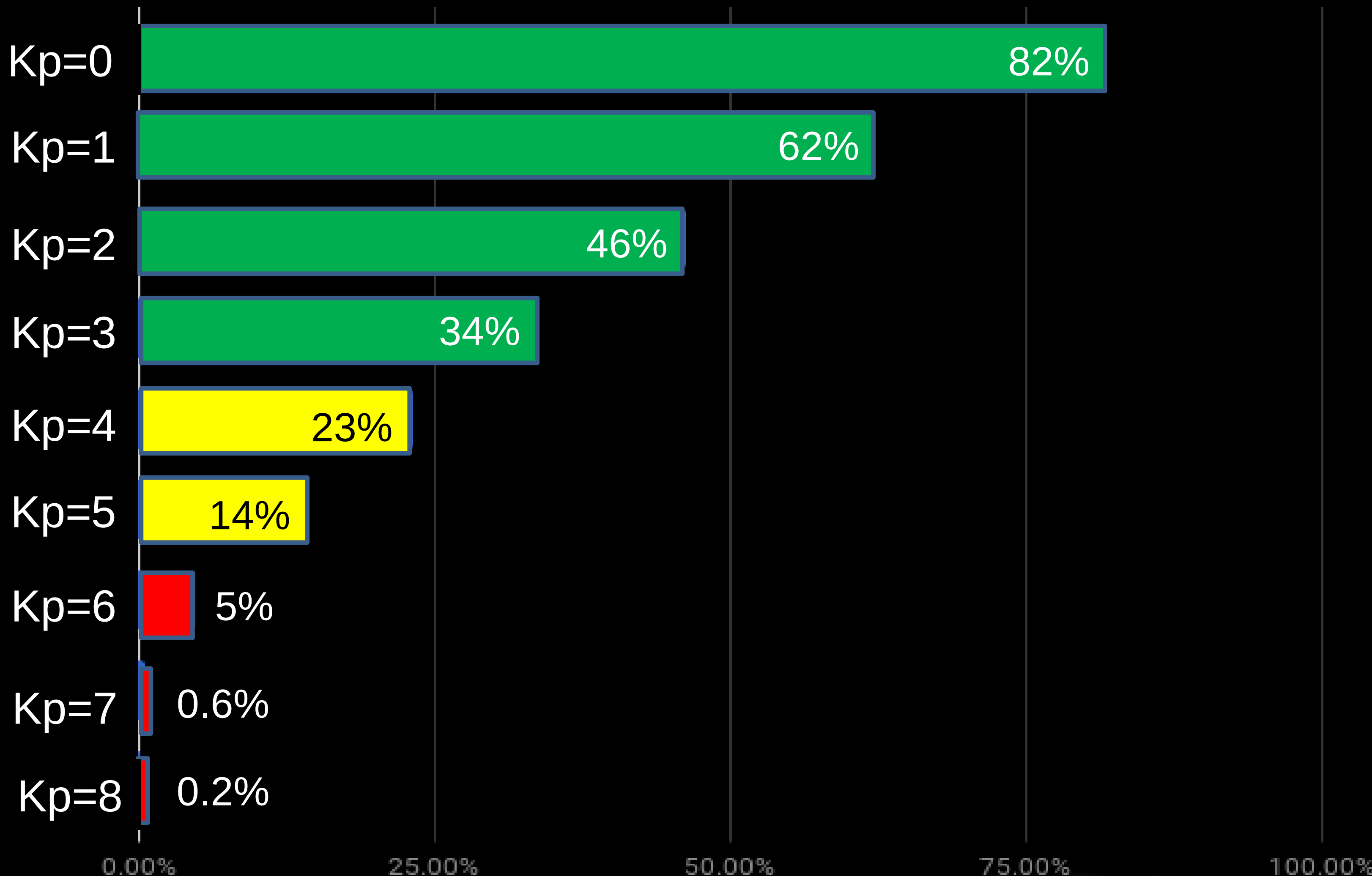
Unstable HF ionospheric propagation at high latitudes for a few hours

Days per Year with Geomagnetic Storms



Daily Variability of Geomagnetic Disturbances

Likelihood on any given day that Kp will exceed

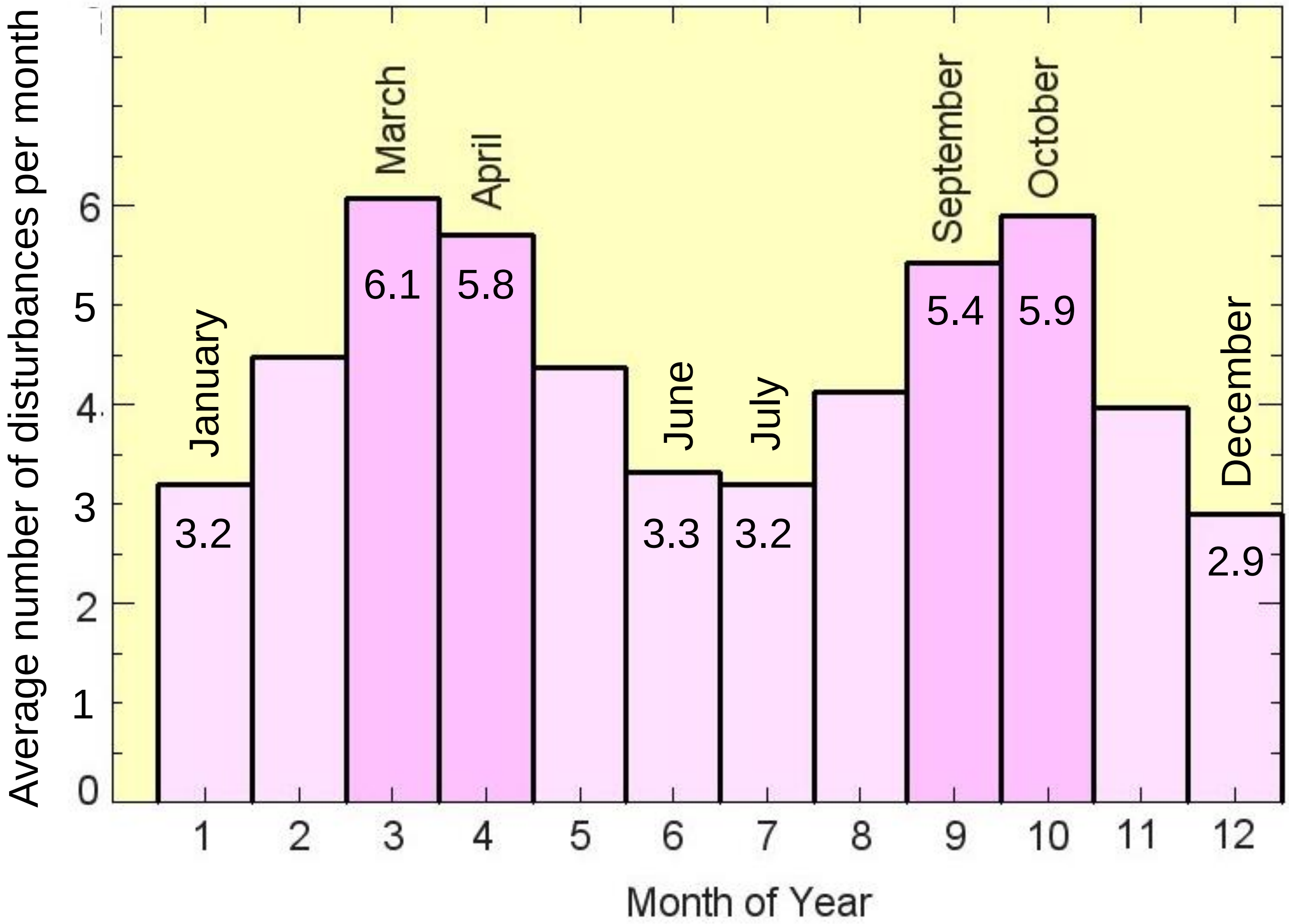


Data Source: British Geological Survey

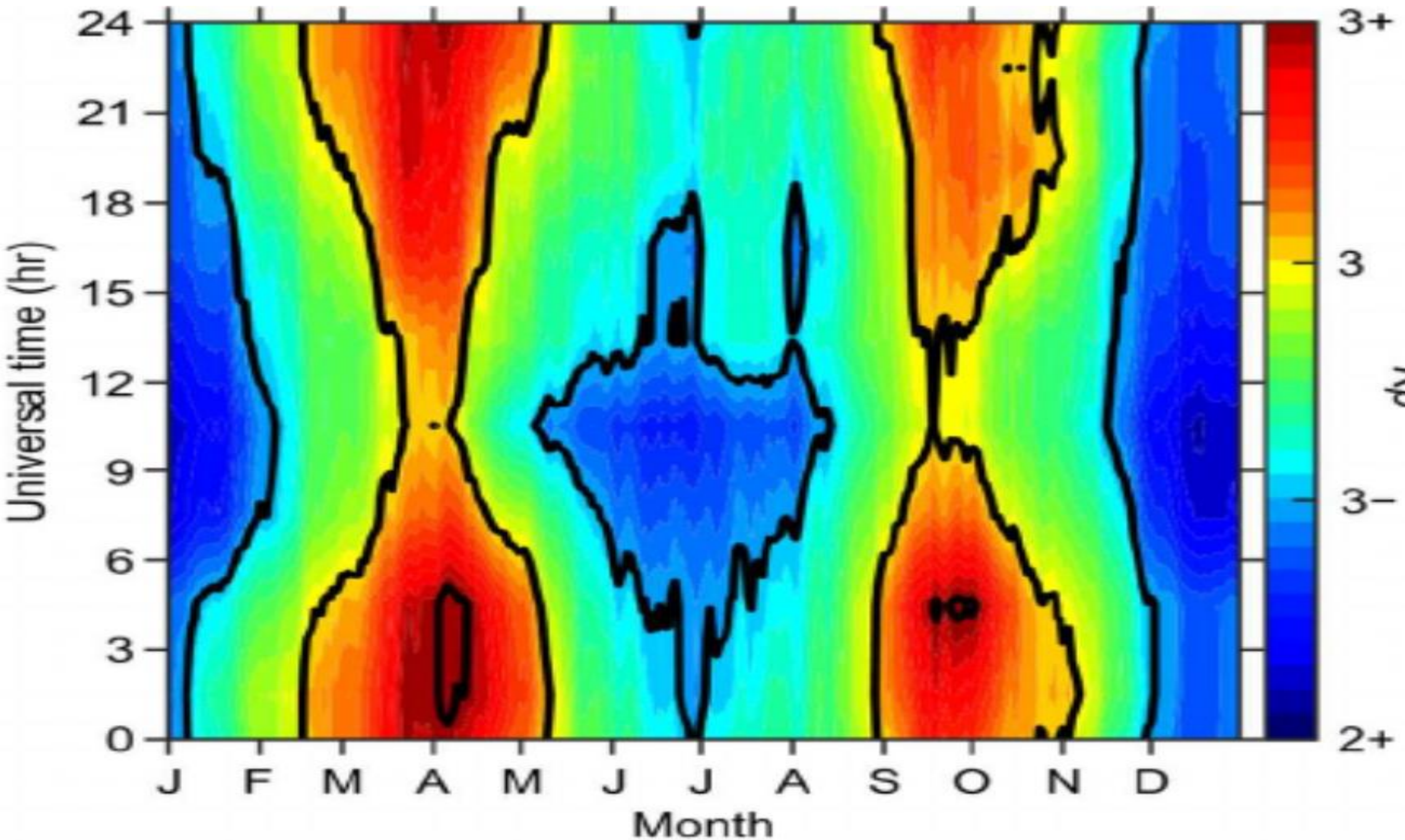
SeeTheAurora.com

Seasonal Variability of Geomagnetic Disturbances

Geomagnetic disturbances (Kp=4+) are about twice as likely during spring and fall compared to summer and winter



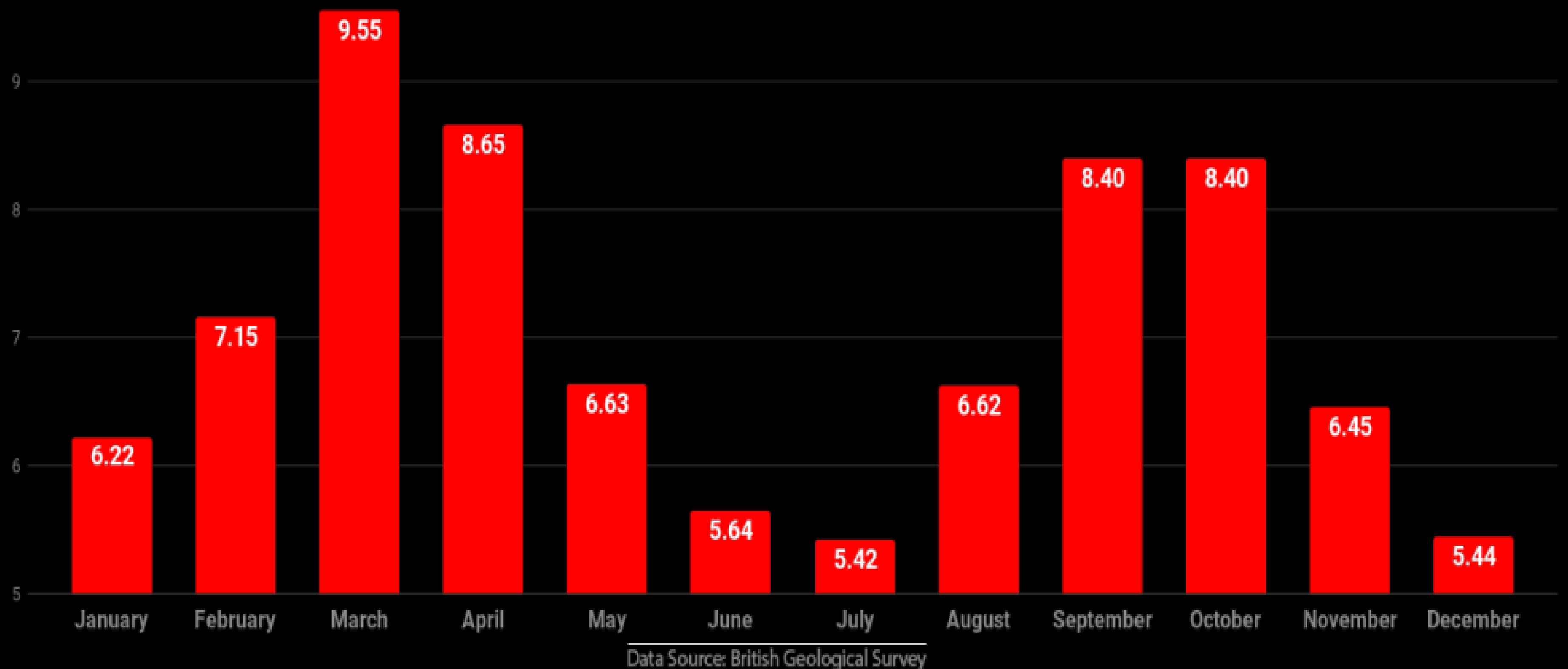
Northern Hemisphere Kp index
Seasonal and Time Dependence



Seasonal Variability of Geomagnetic Storms

Geomagnetic storms are about twice as likely during spring and fall compared to summer and winter

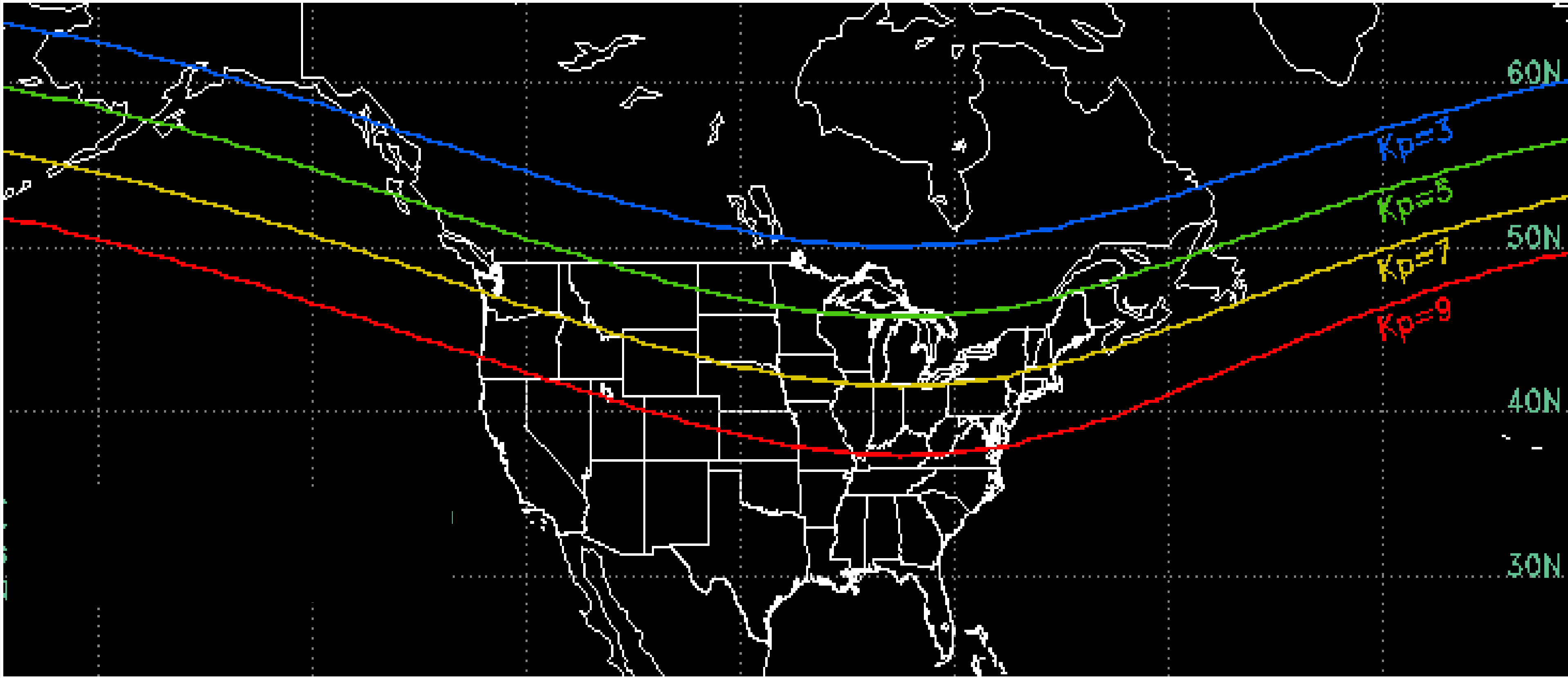
Average geomagnetic storm (Kp=5+) days per month



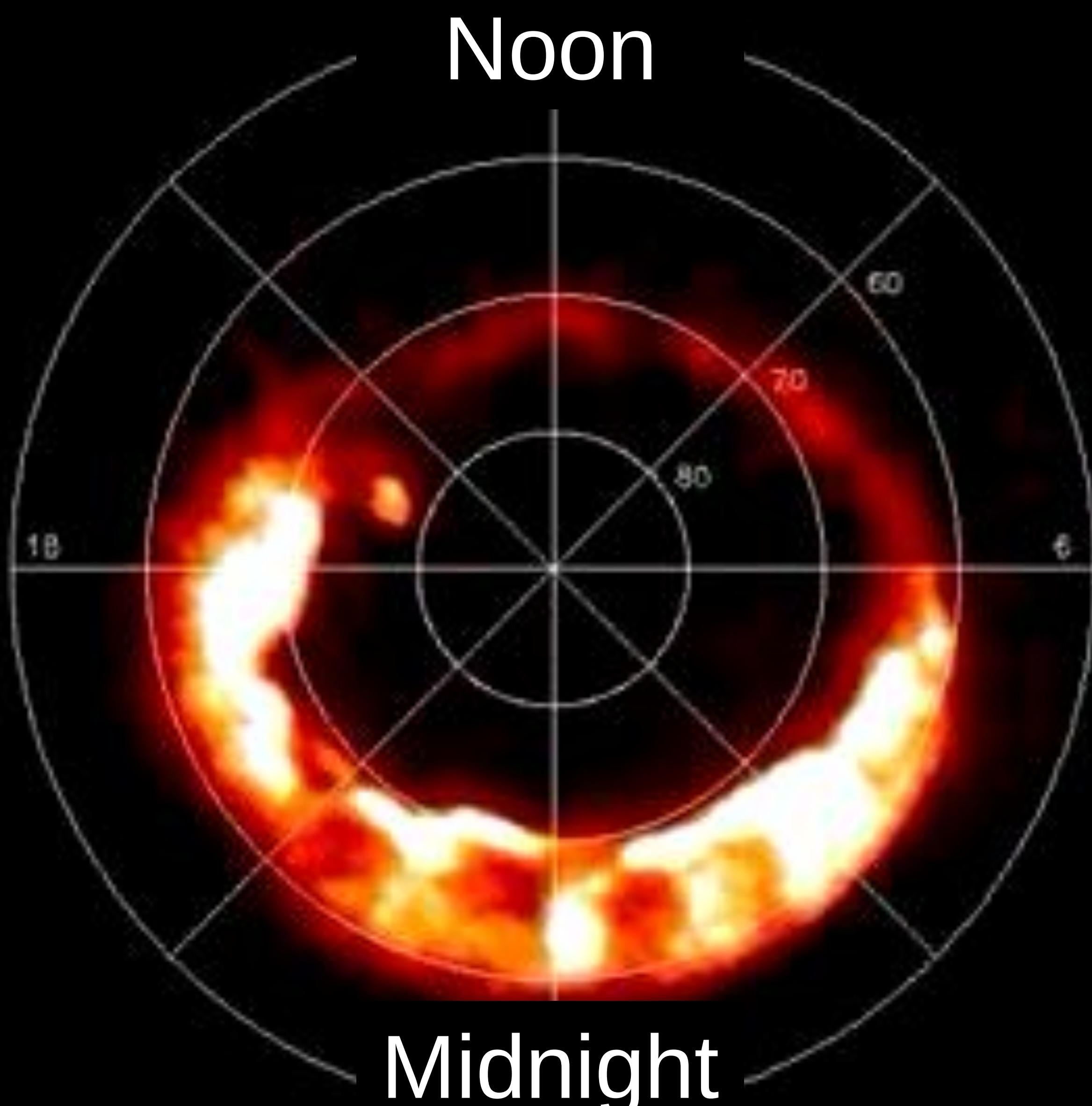
Absorption in the Auroral Oval D-Region caused by geomagnetic storms

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

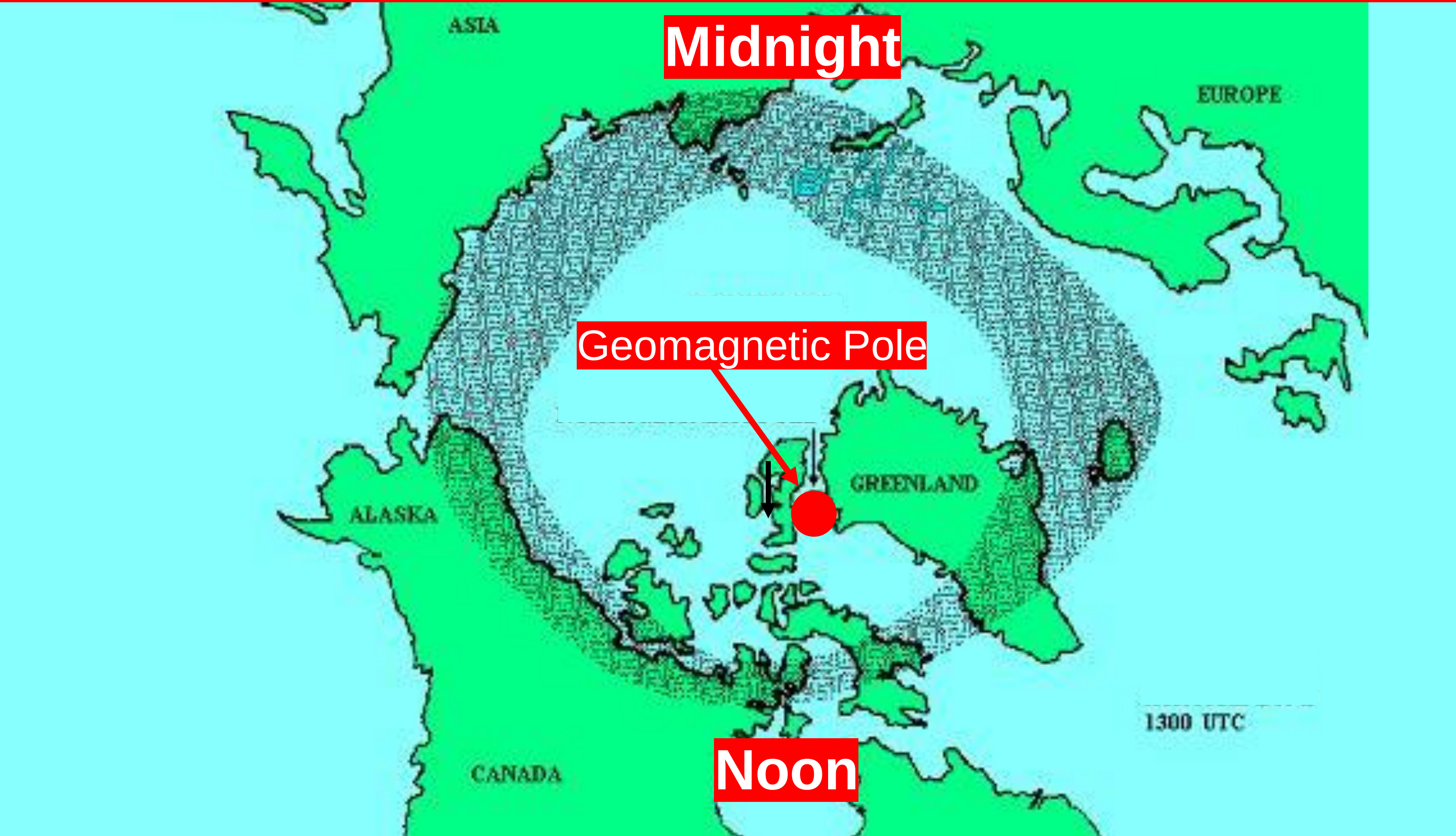


Aurora over the North Pole



Aurora over the United States and Canada
Midnight   March 15, 1989

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



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

The night time auroral oval moves equator-wards and its width expands during geomagnetic storms:

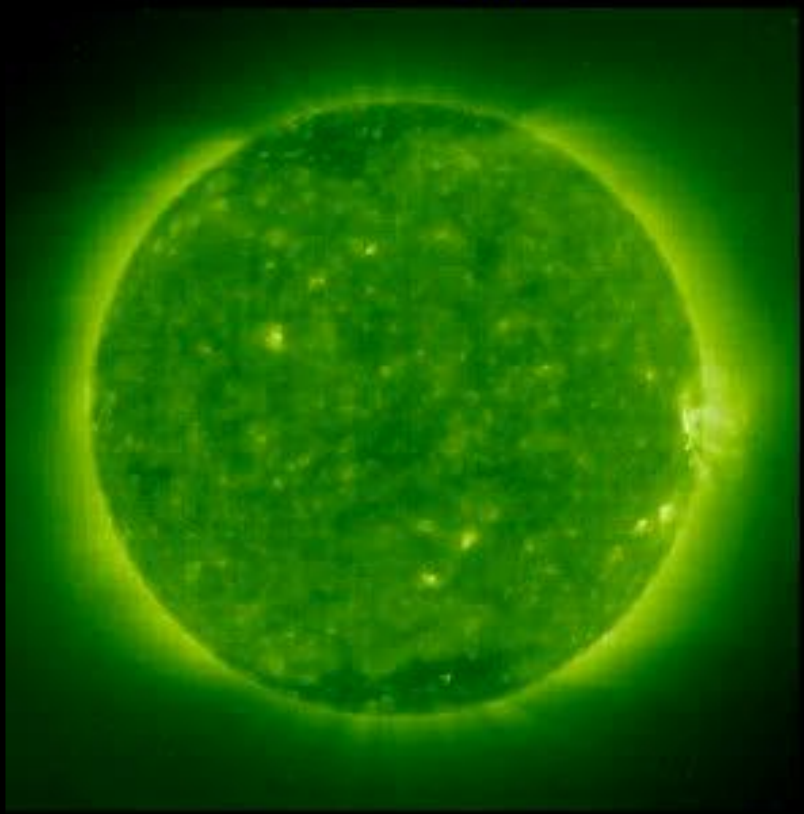
- the enhanced solar wind pulls the Earth's nightside open magnetic field lines further toward the equator
- shifting the auroral zone closer to the northern U.S. border

Absorption in the auroral oval caused by geomagnetic storms begins at about midnight at reflection points in the auroral oval

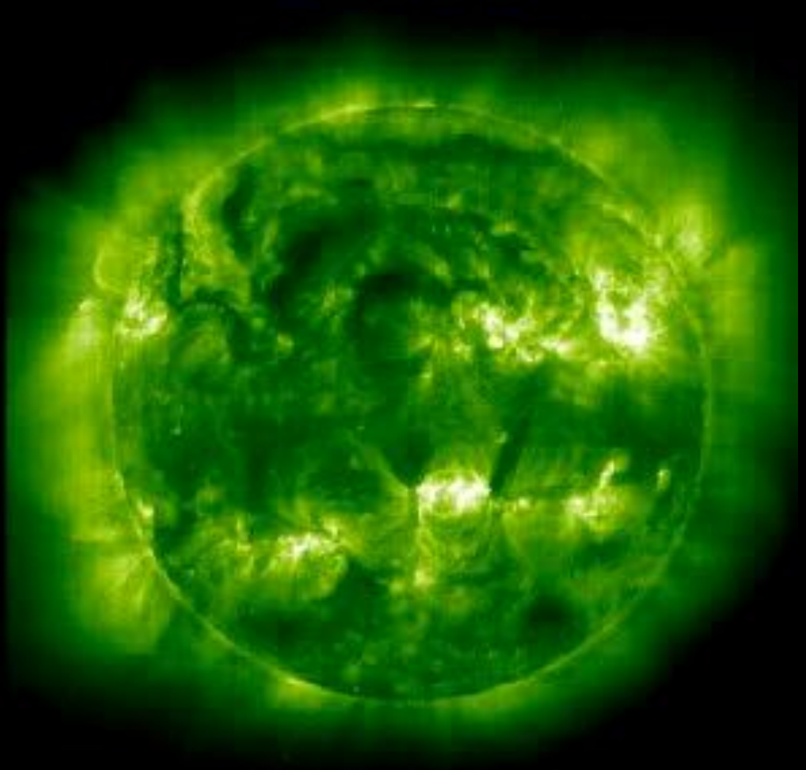
Normal daytime D region absorption caused by ionizing solar radiation is almost always stronger than auroral absorption caused by geomagnetic storms after sunrise at the reflection points in the auroral oval

More Frequent X-Class and Strong M-Class Solar Flares during the seven most active years of the solar cycle

Solar Minimum



Solar Maximum



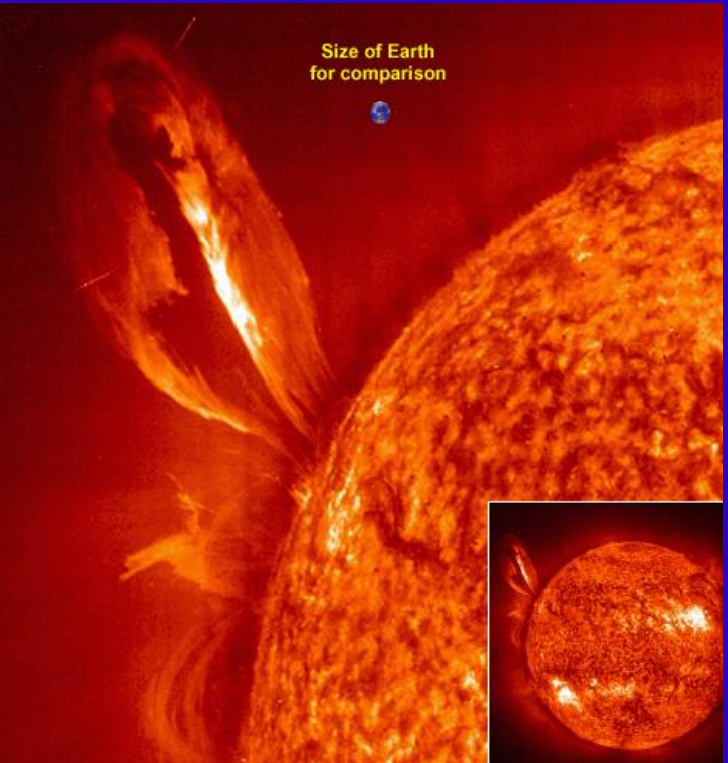
cause moderate to severe <u>sudden ionospheric disturbances</u>

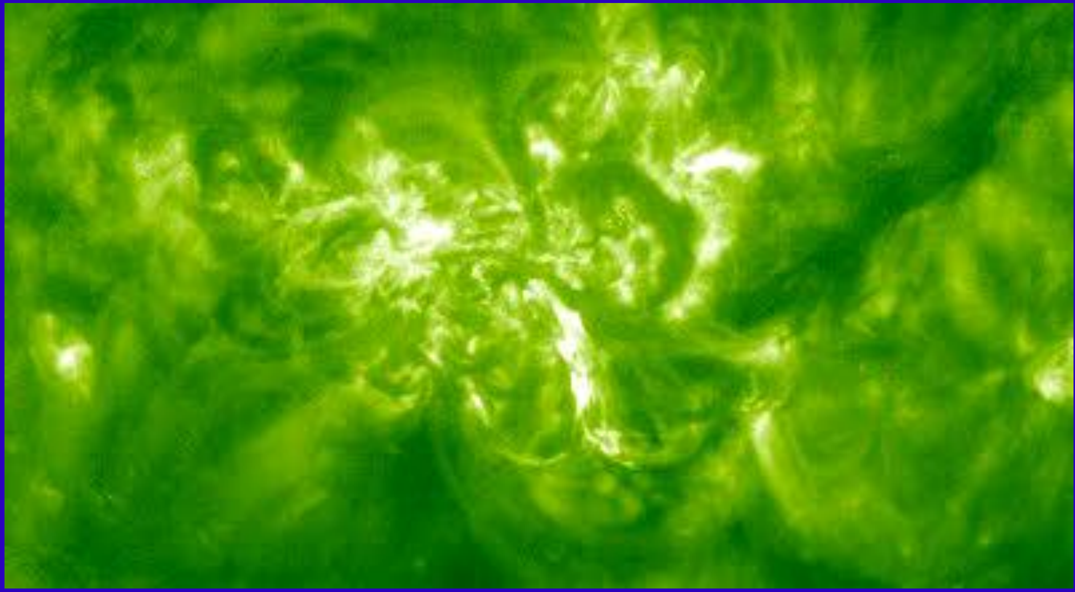
More Frequent X-Class and Strong M-Class Solar Flares

Solar flares accelerate suddenly and without warning from solar active regions

X-class and strong 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

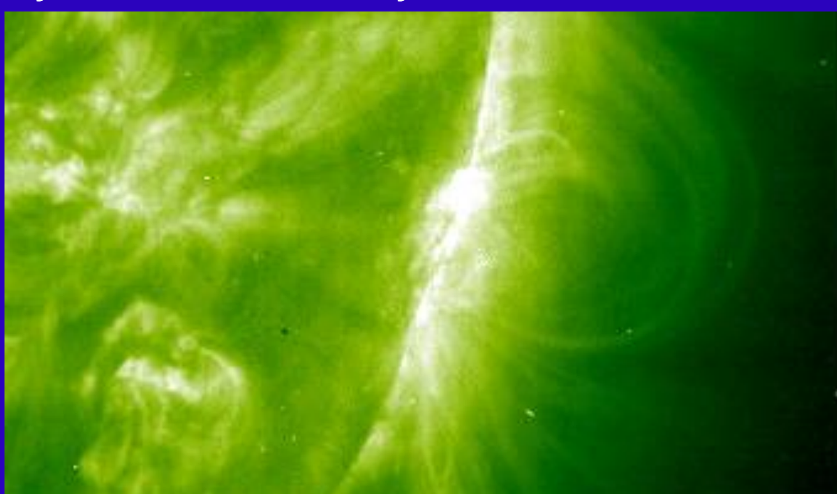
X-Class Solar Flares

X-class flares severely impact HF ionospheric propagation

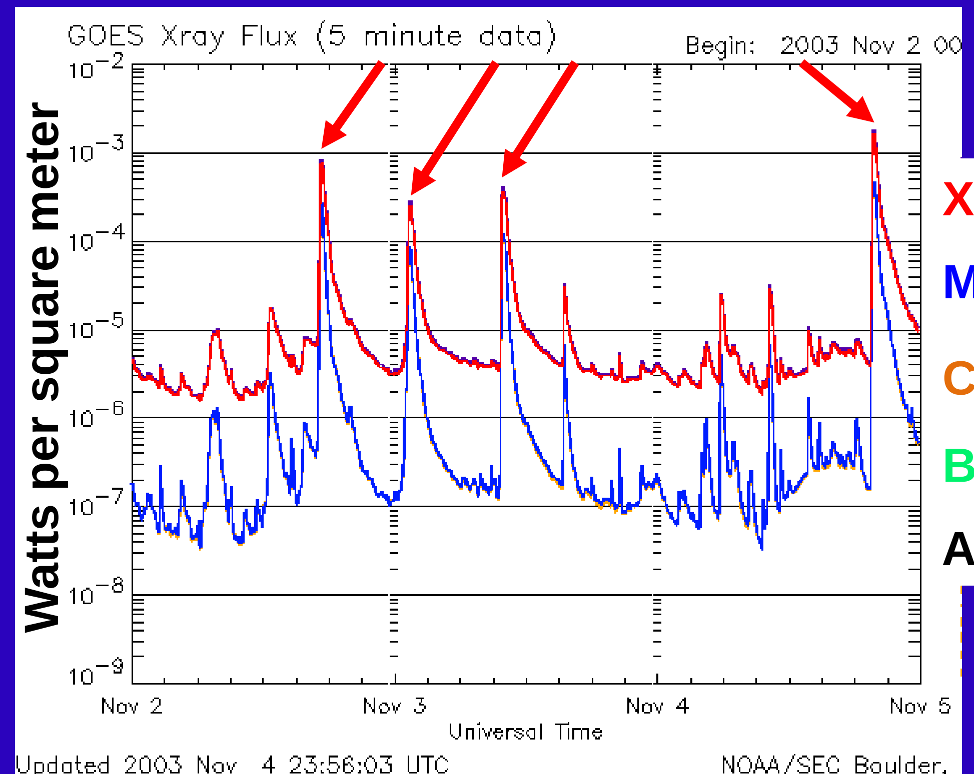
X10-Class – extreme flares produce long duration planet-wide radio blackouts

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

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



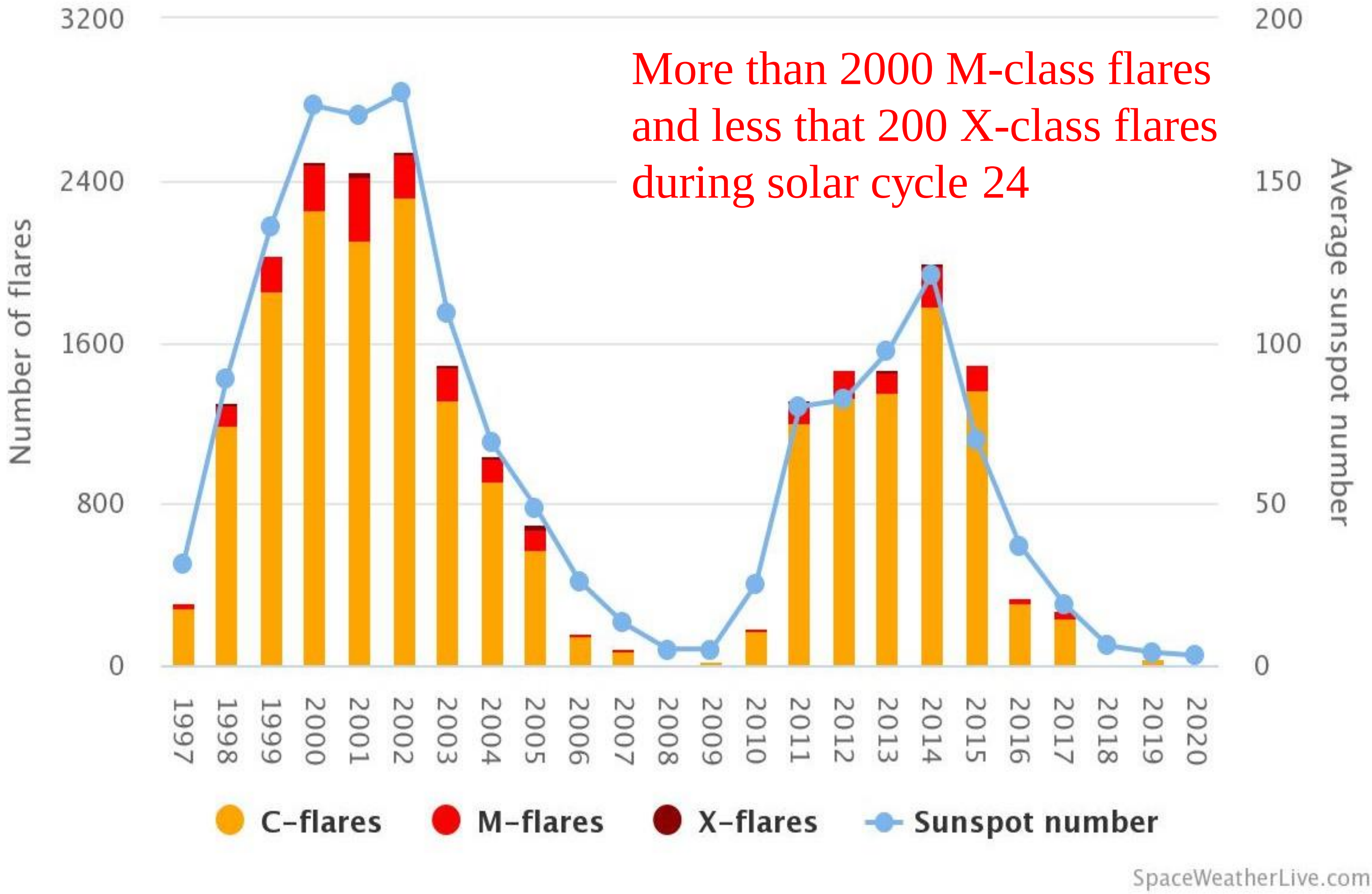
X28 flare -- the largest ever recorded erupts on November 4, 2003



Four X-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 CQs heard in North America 0500Z

	● Spotter (de)	● Spotted (dx)
callsign	spotter-callsign	spotted-callsign[,spotted-callsign]
dxcc	any	any
itu zone	any	any
cq zone	any	any
continent	NA - North America	EU - Europe

http://beta.reversebeacon.net/main.php