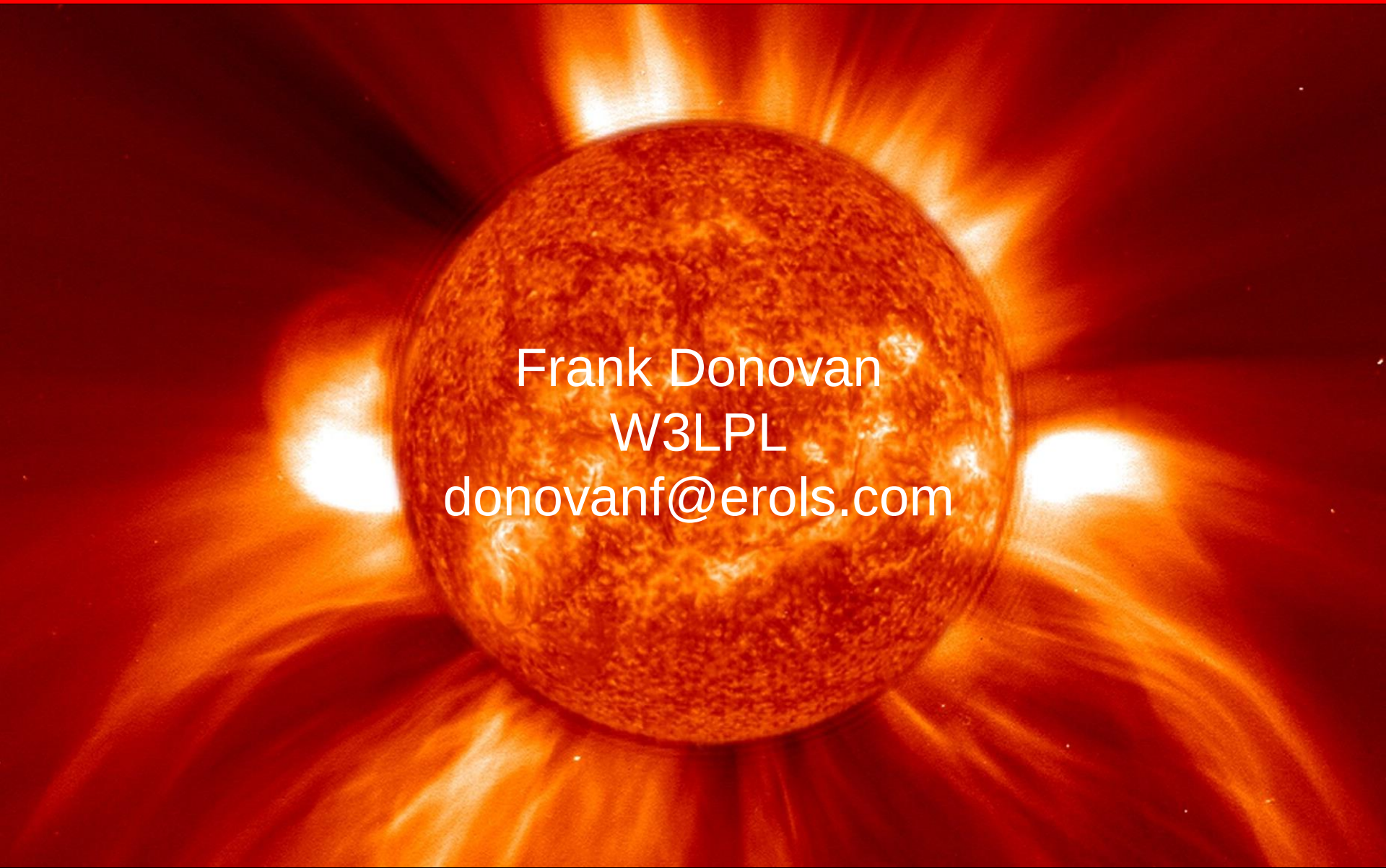
Worldwide HF Propagation
During the Next Three Years of Solar Maximum



Frank Donovan
W3LPL
donovanf@erols.com

Experience the Wonders of Solar Cycle 25's Solar Maximum

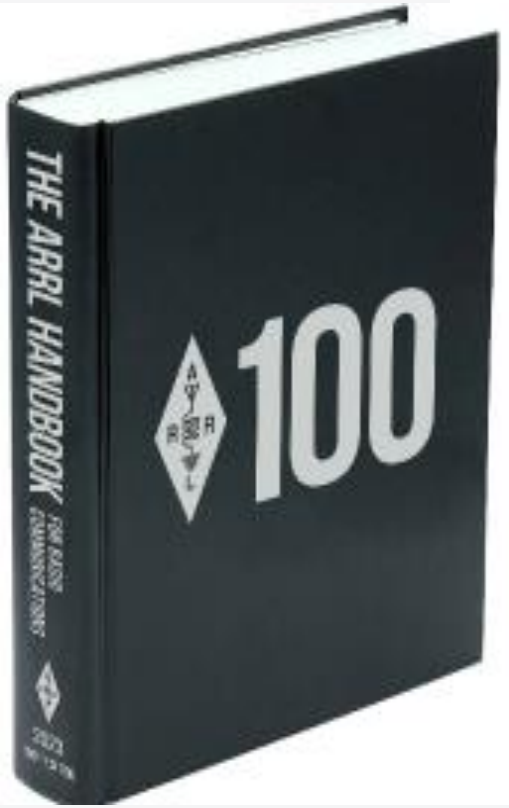
The next three years of this solar cycle will continue to produce the best HF and 6-meter DX propagation in 20 years

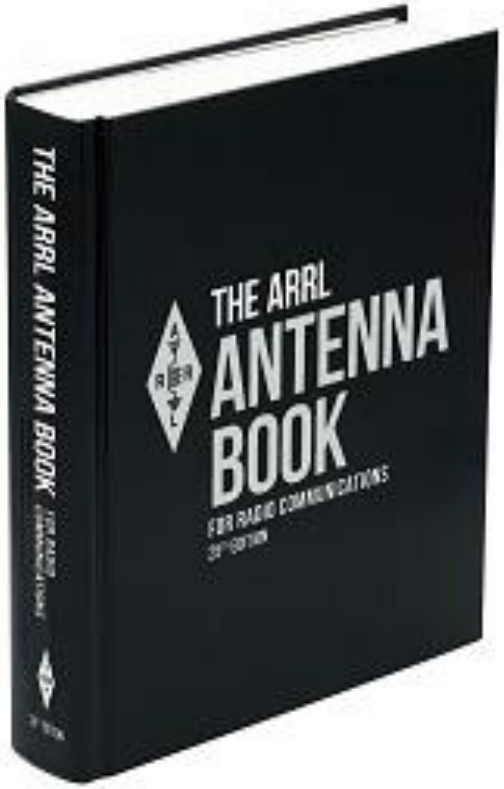
Frank Donovan W3LPL

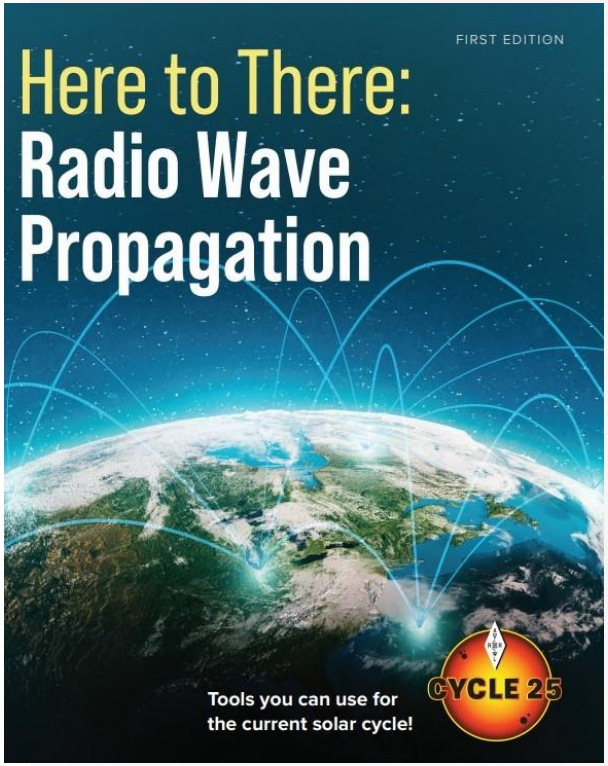
May 2023 QST

arrl.org/qst

The Three Most Valuable Investments to Greatly Improve Your Detailed Knowledge of Antennas and Propagation







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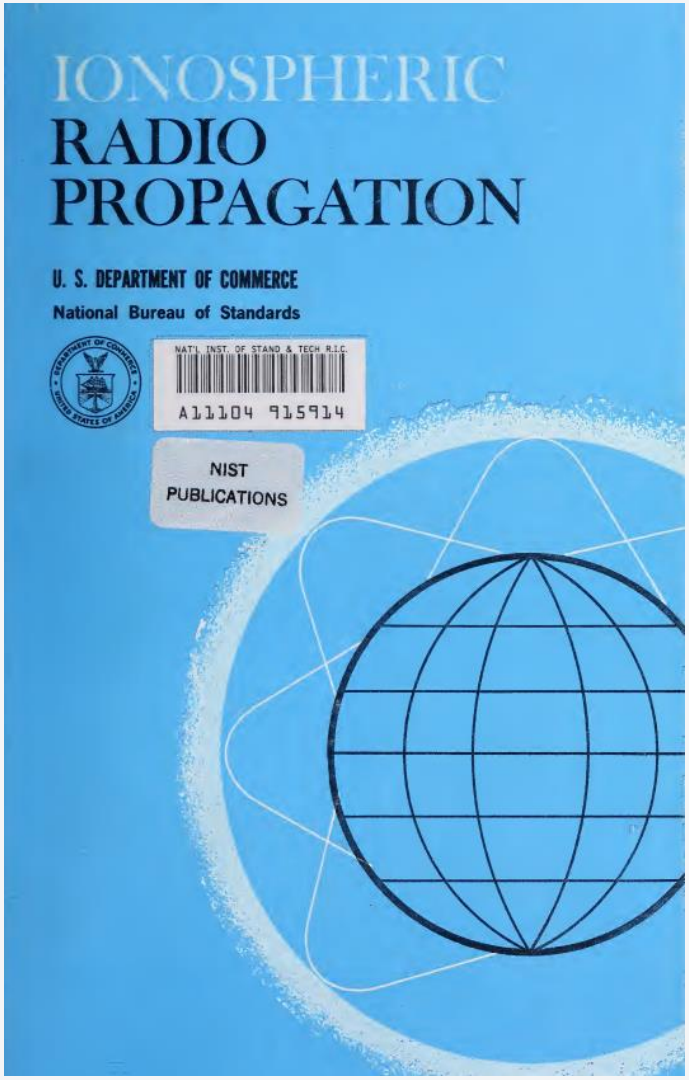
An Excellent Free Technical Reference for Scientifically Inclined Amateurs



nvlpubs.nist.gov/nistpubs/Legacy/MONO/nbsmonograph80.pdf

Propagation Related Features of the Sun

Solar Magnetic Field Drives All of these Features

Magnetic Field: creates the corona and IMF
Corona: Superheated magnetized plasma
Active Regions: sunspots, solar flares, CMEs
Sunspots: concentrated closed magnetic fields
Solar Cycles: solar maximum and solar minimum
Solar Wind: megatons/sec of magnetized plasma
Coronal Holes: origin of high speed plasma flows
CMEs: explosions of magnetized plasma
Solar Flares: minutes of intense X-ray radiation

Key Features of the Sun-Earth System

every HF operator should understand these basic concepts

Sunspots and Active Regions Intense closed magnetic fields emerge from the Sun to form sunspots and their surrounding active regions. Ionizing extreme ultraviolet radiation, ionizing energetic hard x-rays, solar flares and coronal mass ejections emerge from active regions

Solar Cycles Duration varies from 9 to as much as 14 years
Some cycles have a long lasting and more energetic solar maximum
Some cycles have a long lasting and deeper solar minimum

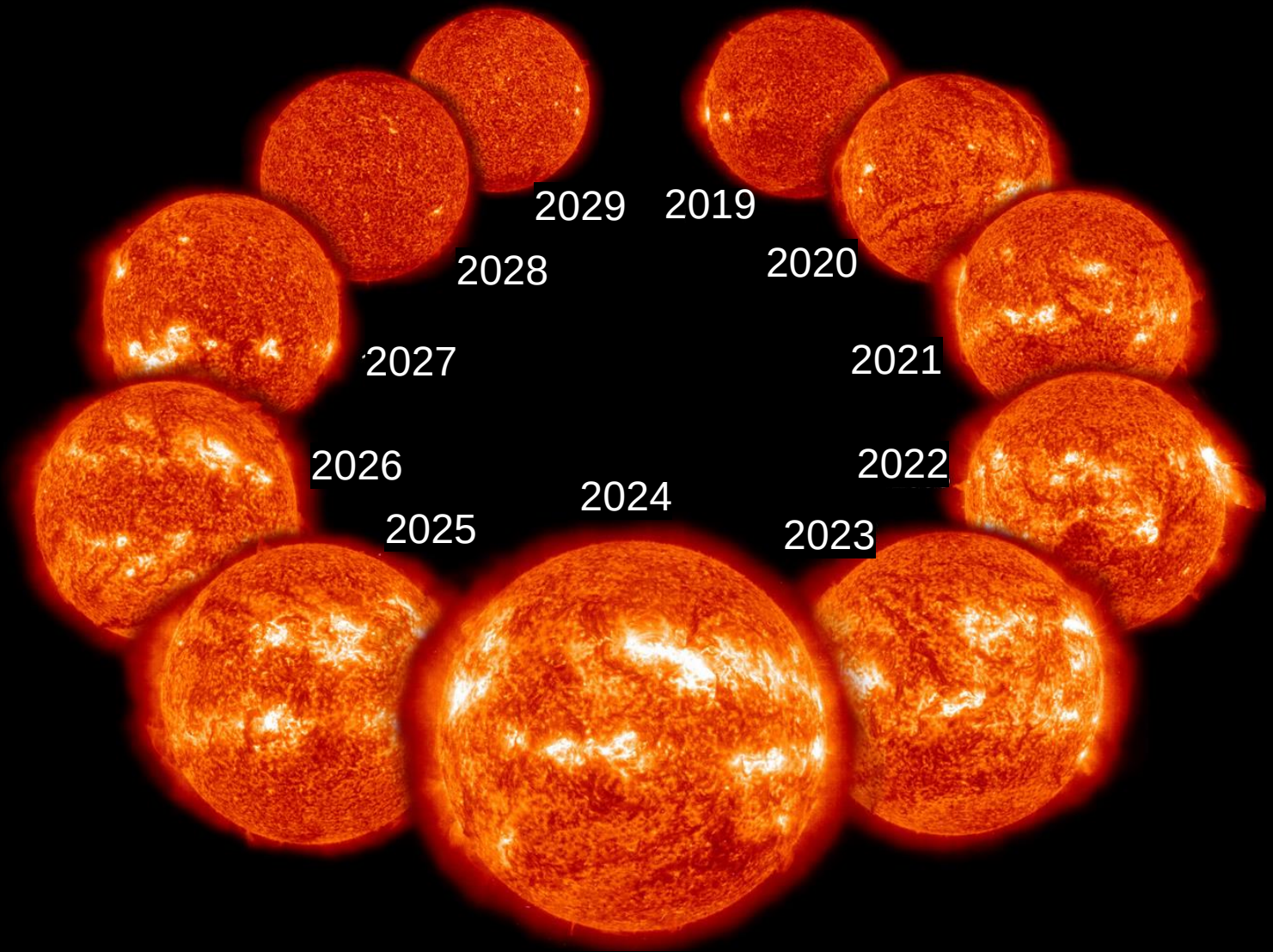
Ionizing Radiation Ten times more ionizing extreme ultraviolet radiation during solar maximum improves HF propagation especially from September through May. Highly energetic x-rays from solar flares can produce up to two hours of daytime radio blackouts with no warning

Geomagnetic Disturbances HF propagation can be degraded by disturbances in the solar wind's hypersonic flow of magnetized plasma

27 Day Solar Rotation 27 day periods of enhancement & disturbance

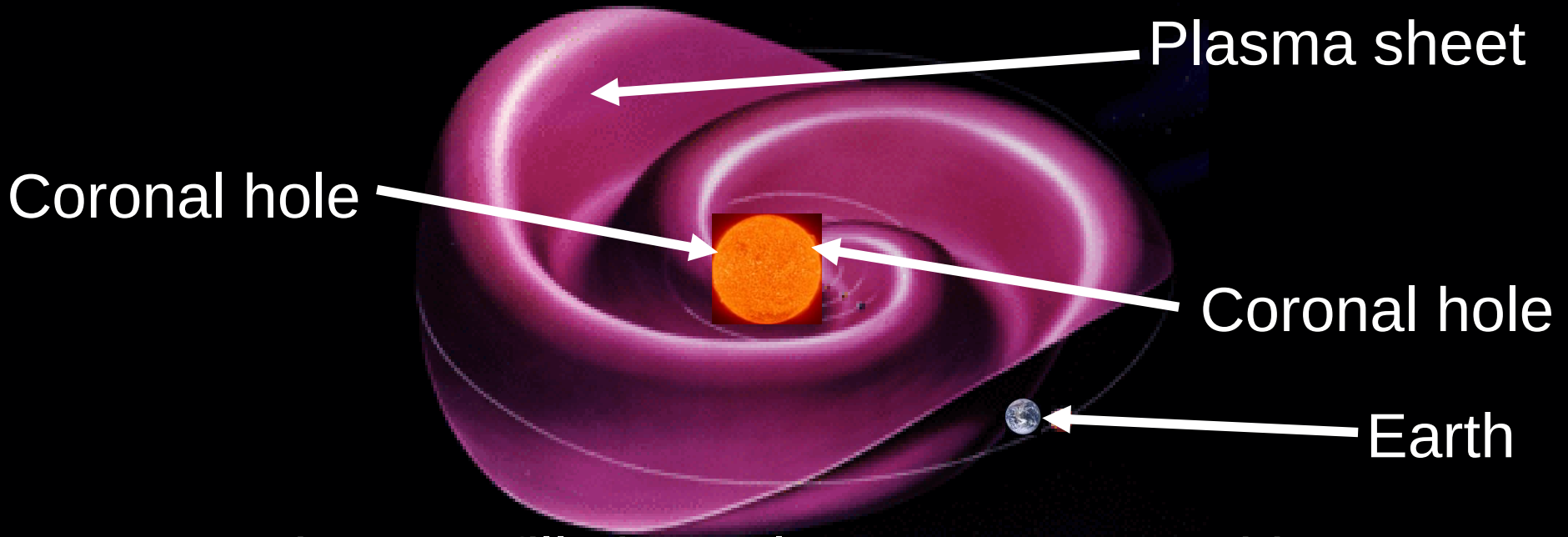
Seasonal Variability Earth’s 23.5º tilted axis reduces the intensity and frequency of disturbed HF propagation during summer and winter and increases (and decreases) ionizing EUV radiation intensity received during mid-latitude and polar region in summer (and winter)

Increased Ionizing Extreme Ultraviolet Radiation Through 2026 Drives Greatly Improved 40 to 10 Meter Propagation



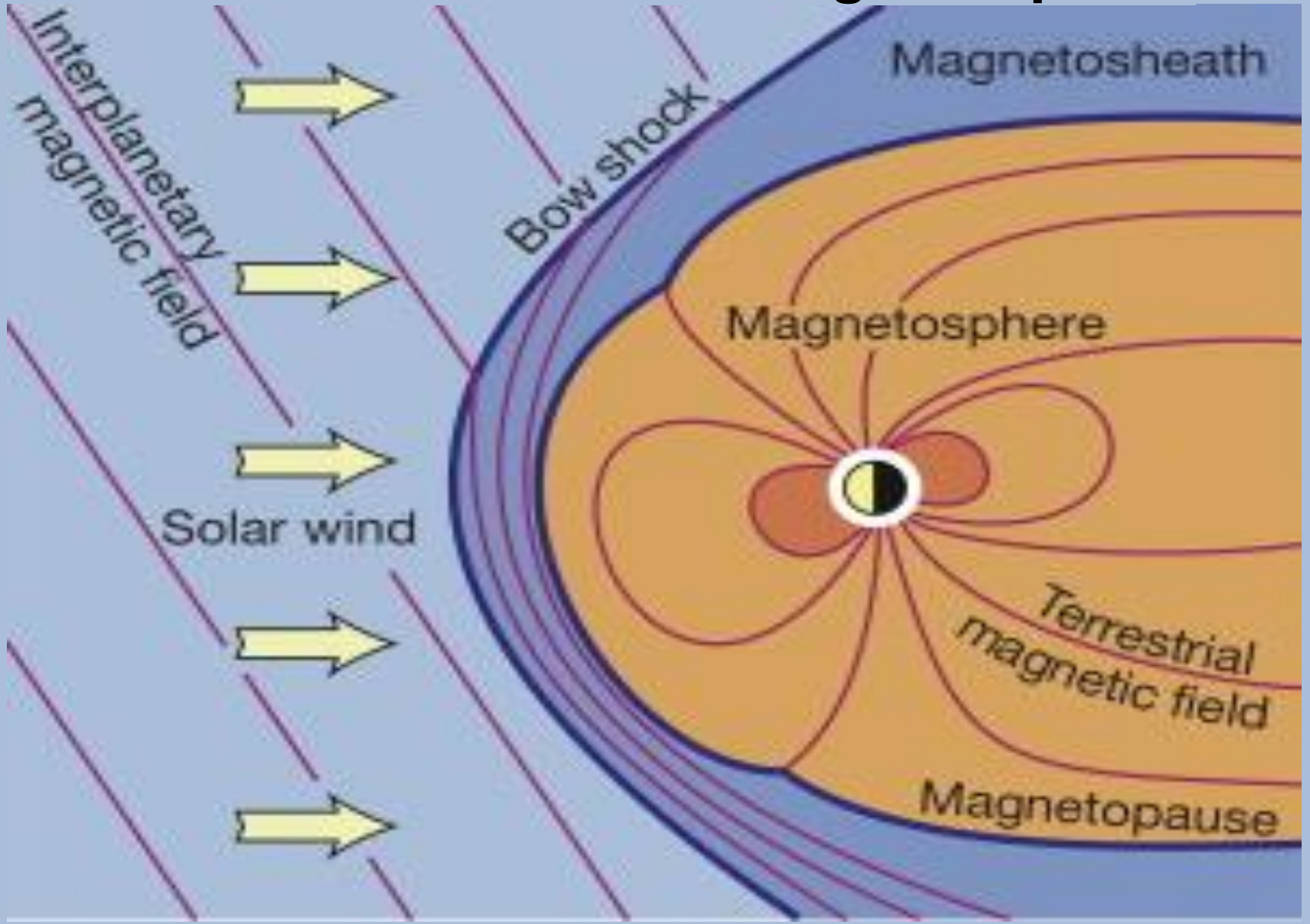
Interplanetary Space

Interactions between fast and slow solar wind
Interplanetary Magnetic Field
Coronal Hole High Speed Streams
Interplanetary Coronal Mass Ejections

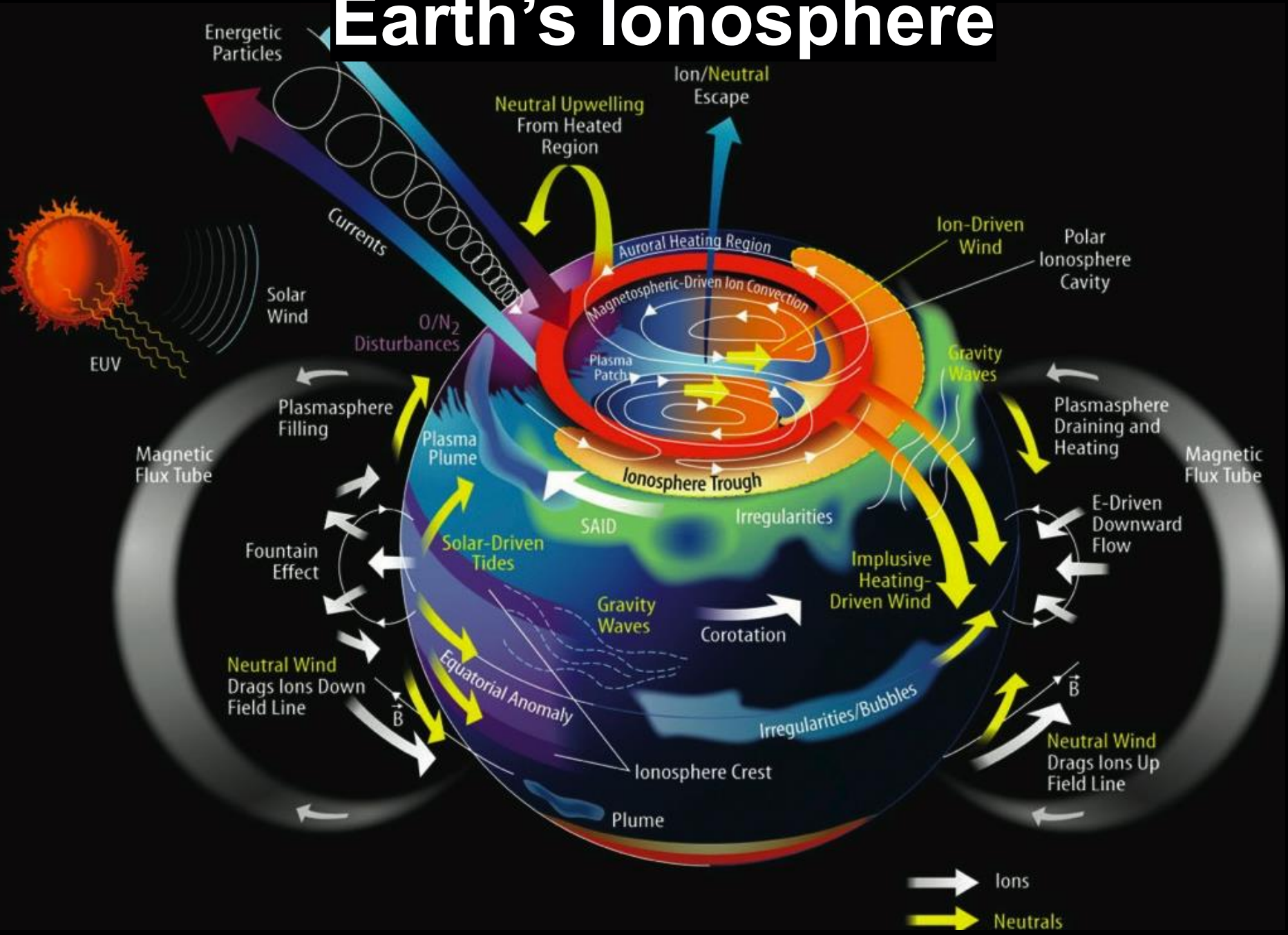


The Sun fills interplanetary space with magnetized plasma, energetic protons, electromagnetic radiation, photon (EUV) radiation and thermal radiation

The Solar Wind and Interplanetary Magnetic Field Collide with Earth's Magnetosphere



Earth's Ionosphere

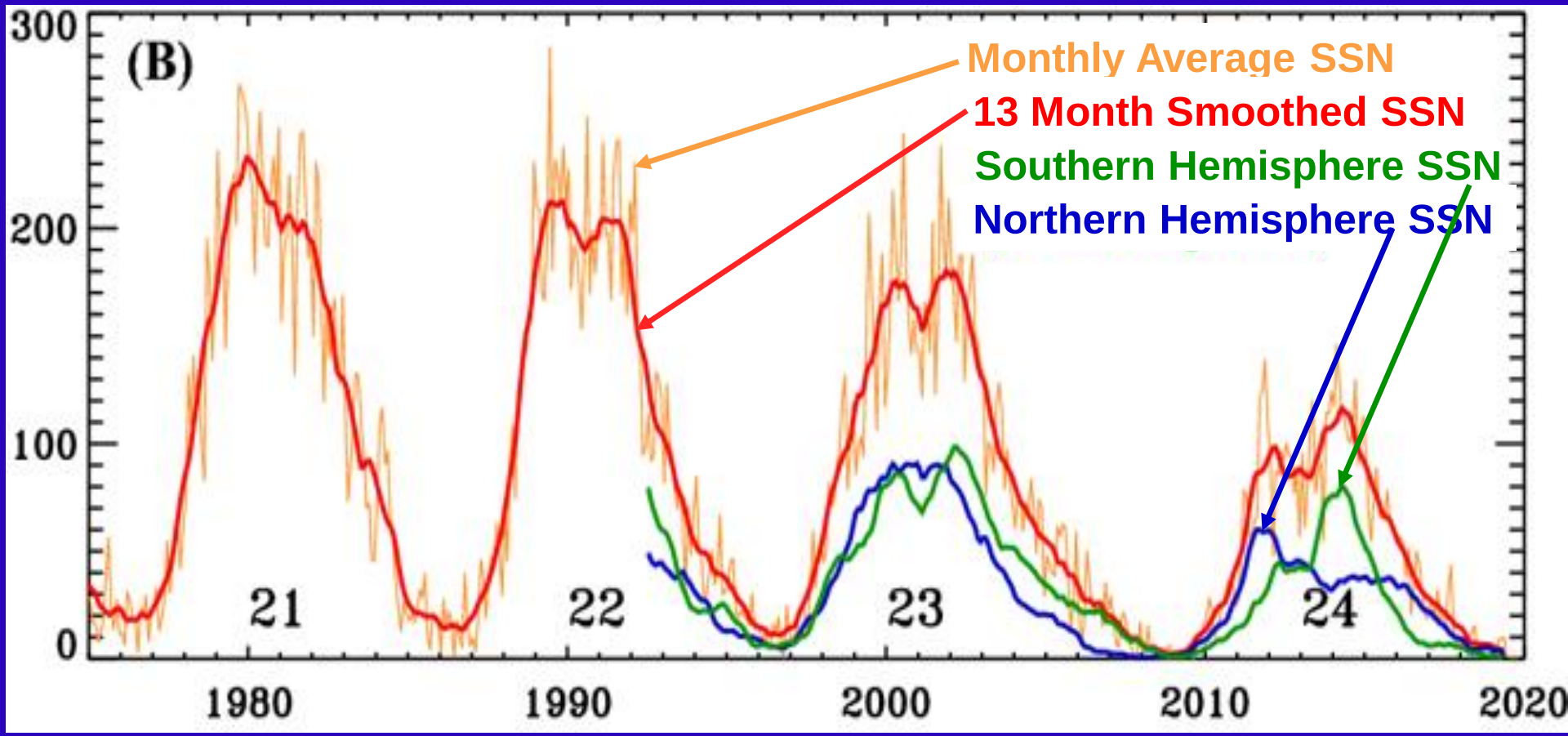


The Solar Cycle's Nominal 11 Year Duration

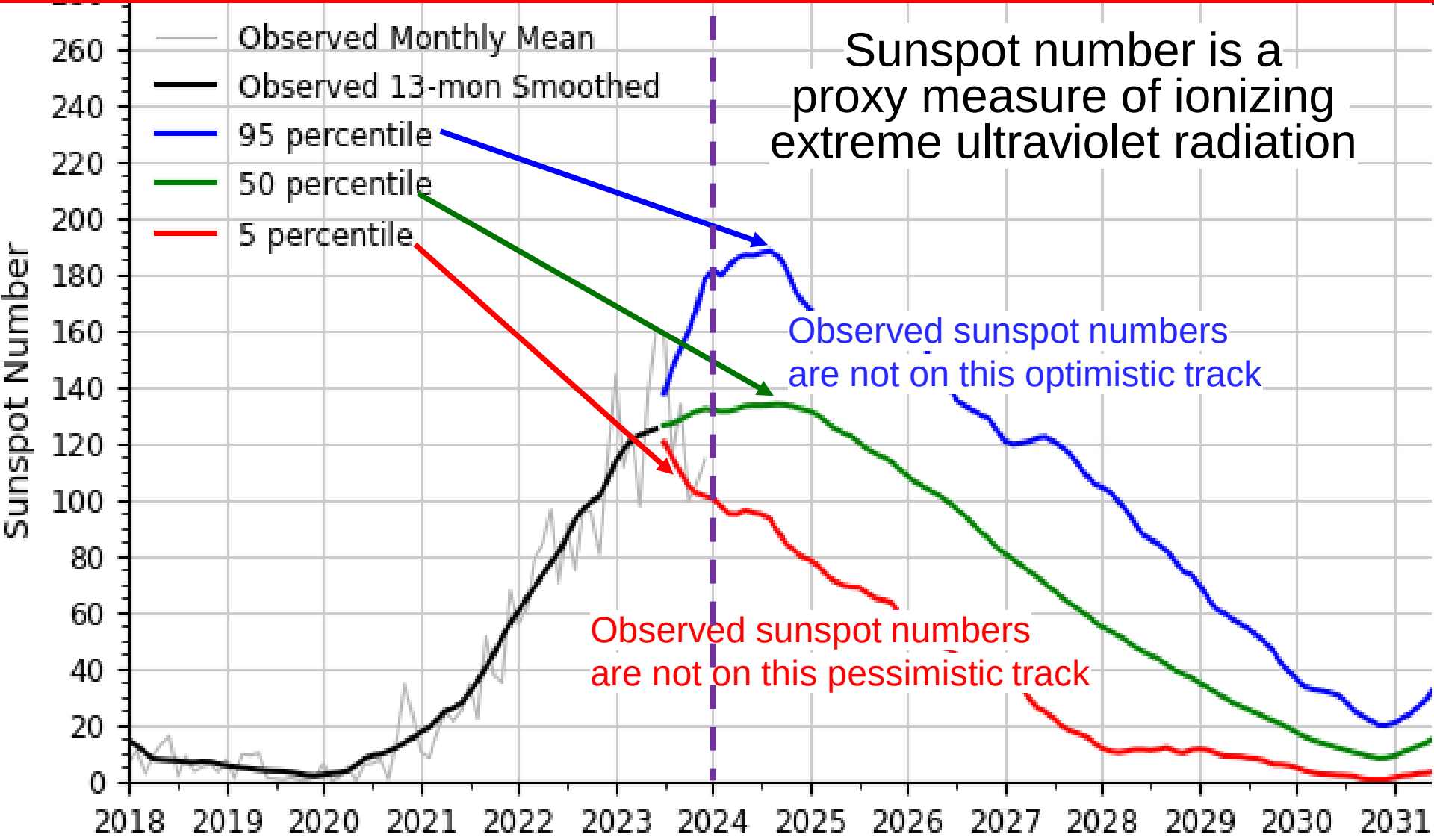
Solar cycle length varies from 9 to 14+ years

The Sun's northern and southern hemisphere solar cycles are sometimes offset by as much as two years

Propagation models use the 13 month smoothed SSN

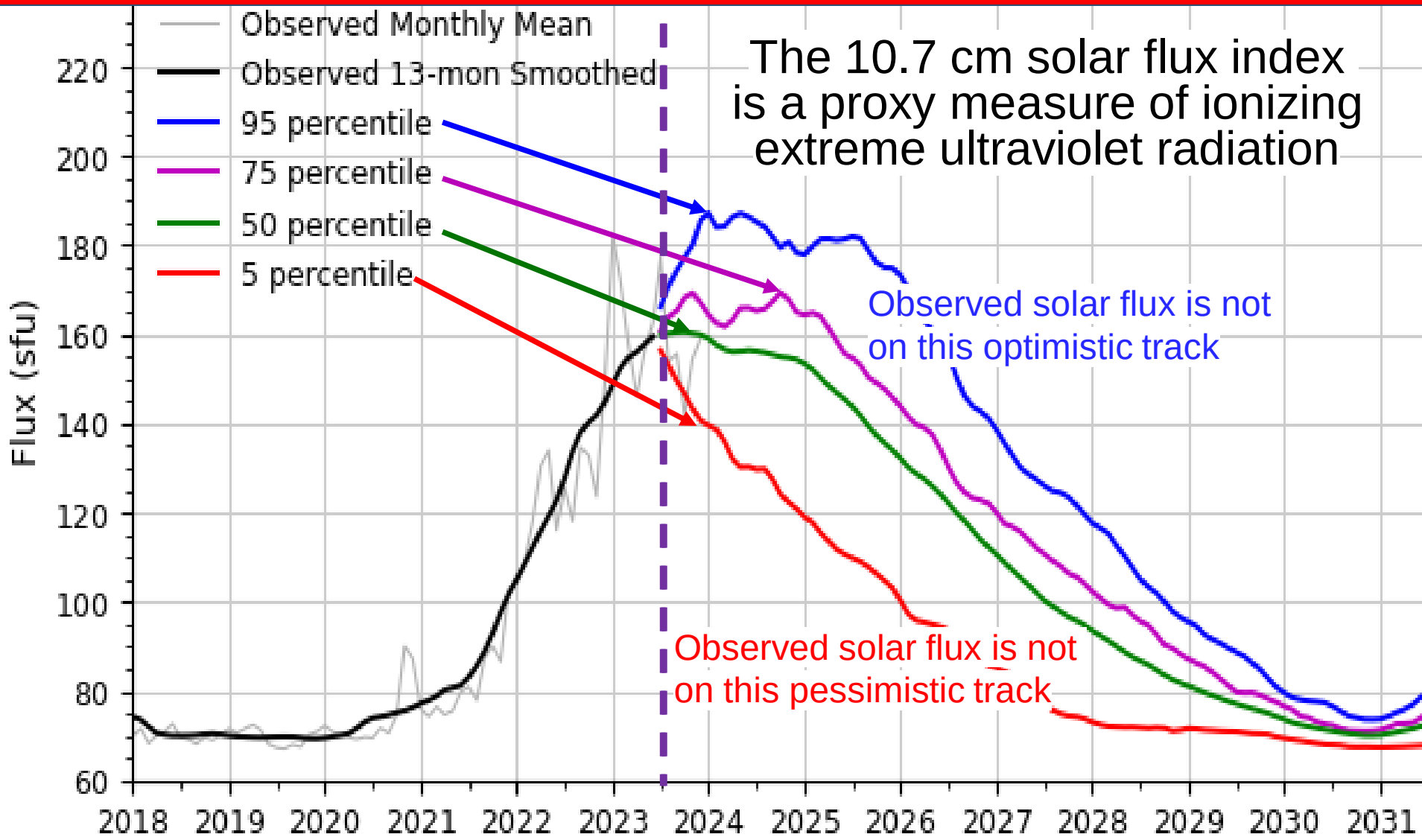


Solar Cycle 25 Smoothed Sunspot Number Forecast
NASA Marshall Space Flight Center - January 2024



www.nasa.gov/msfcsolar

Solar Cycle 25 Solar Flux Index Forecast
NASA Marshall Space Flight Center - January 2024



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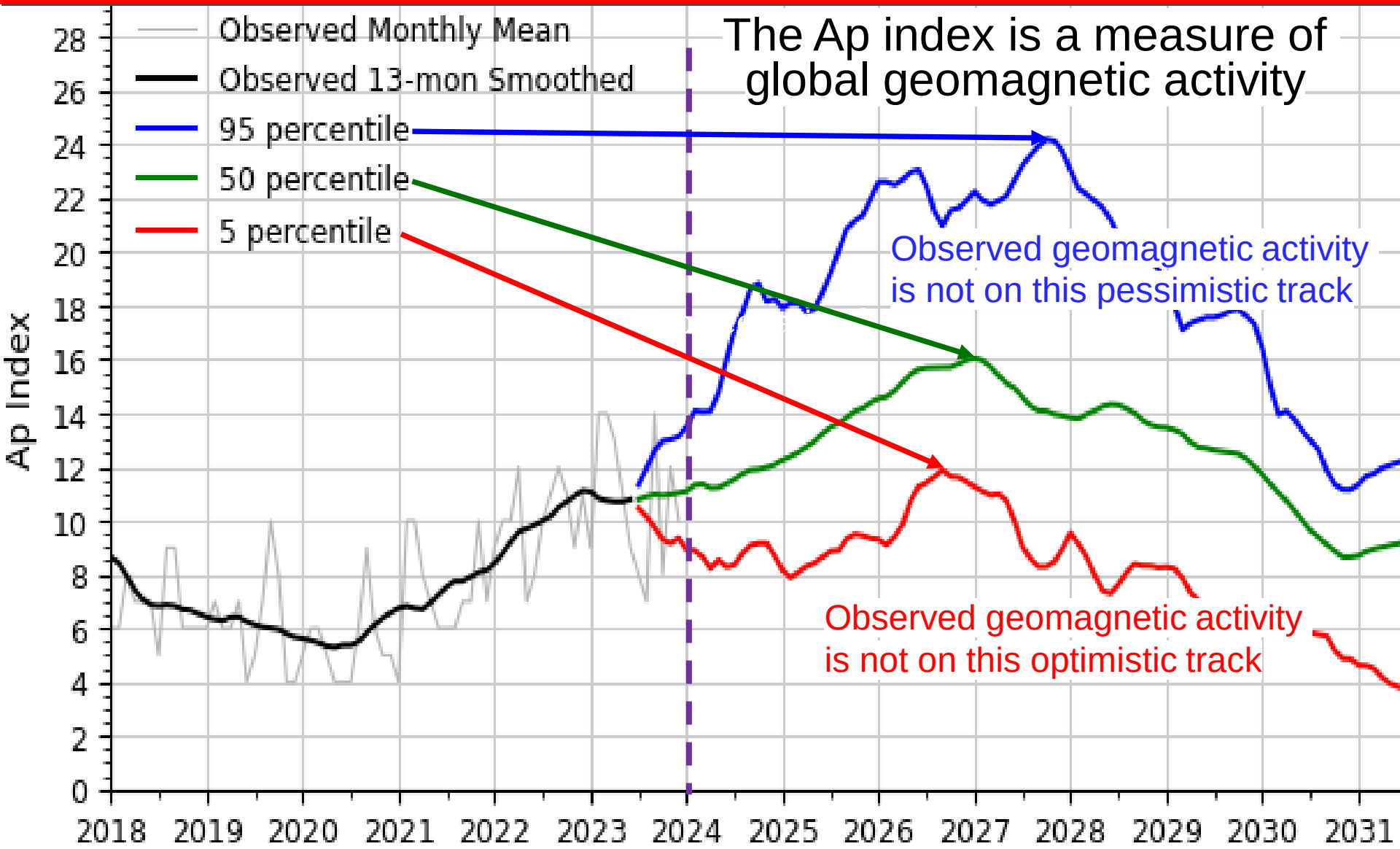
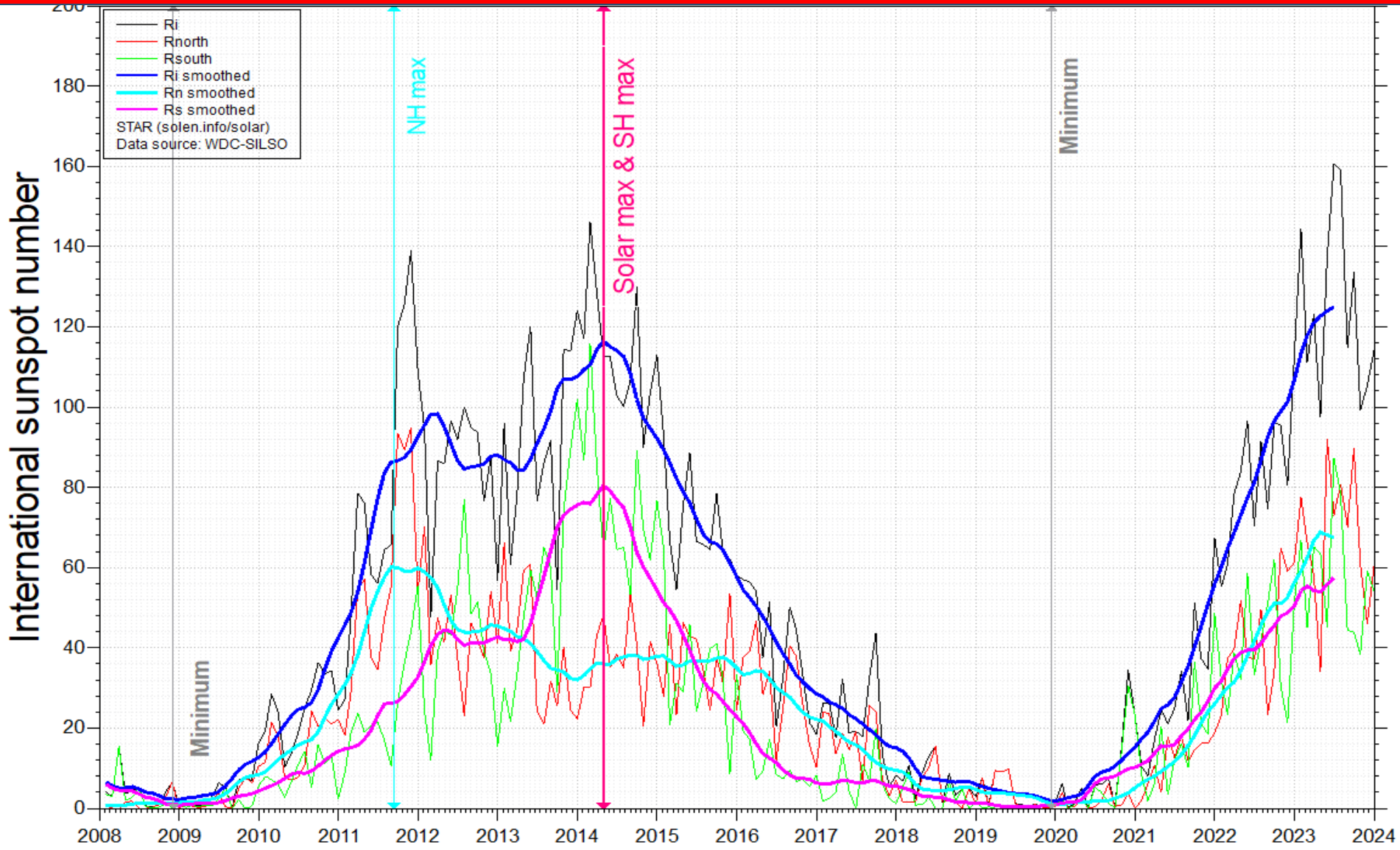
Solar Cycle 25 Geomagnetic Ap Index Forecast
NASA Marshall Space Flight Center - January 2024



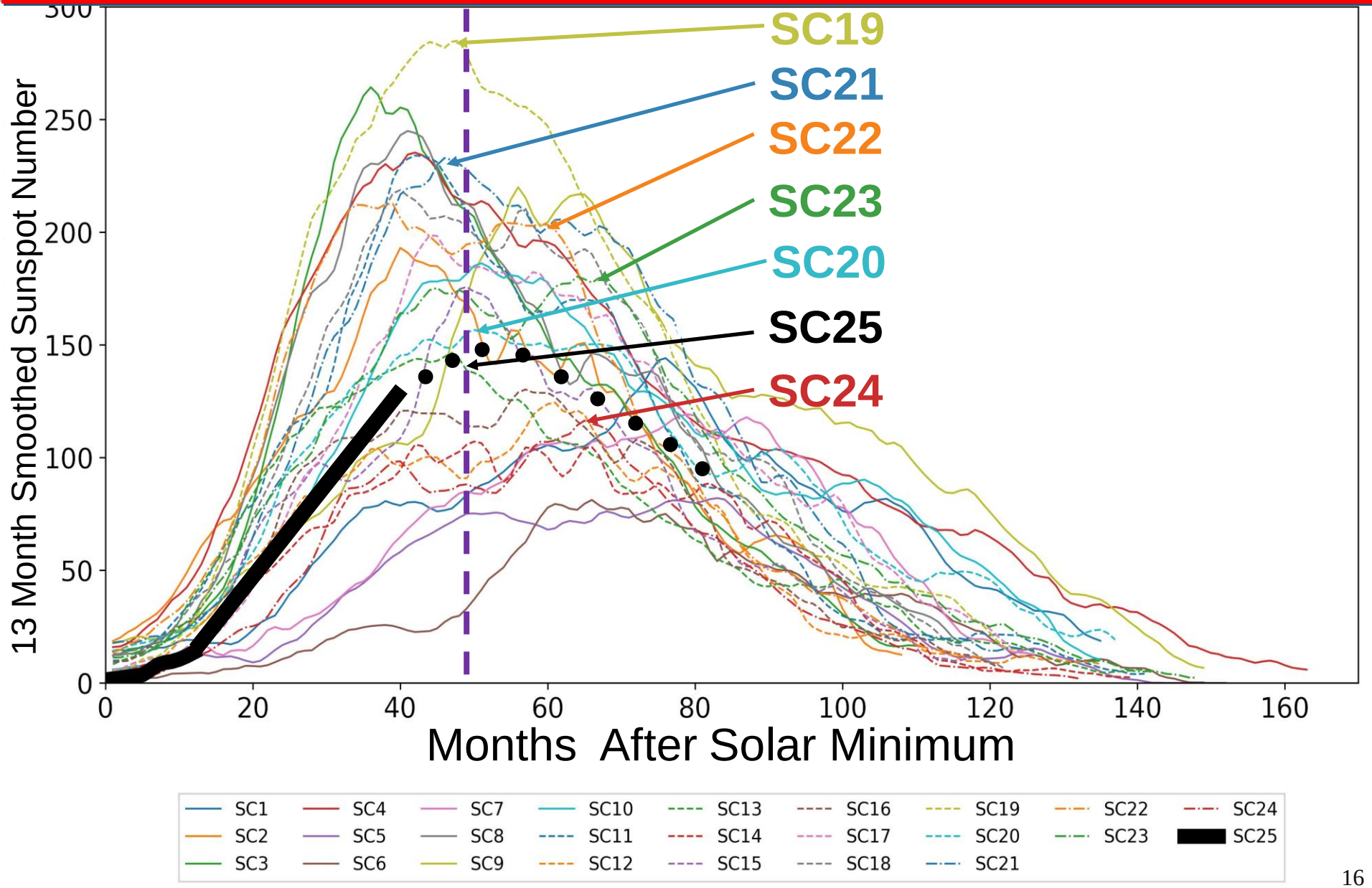
www.nasa.gov/msfcsolar

Solar Cycle 25 Progress vs Solar Cycle 24

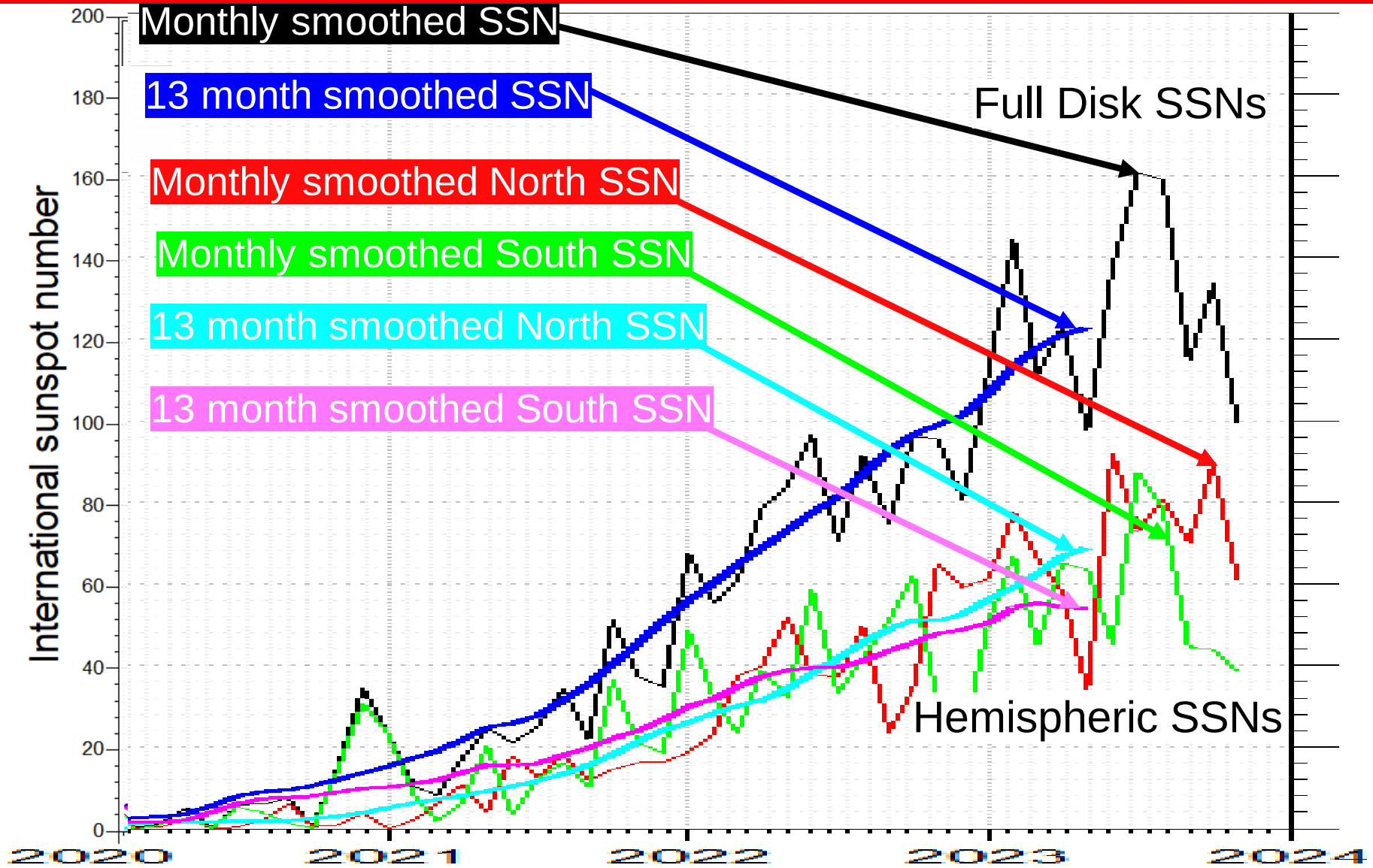


https://solen.info/solar/images/cycle24.png

Solar Cycle 25 Sunspot Activity Increased More Slowly Than All Recent Solar Cycles Except SC24



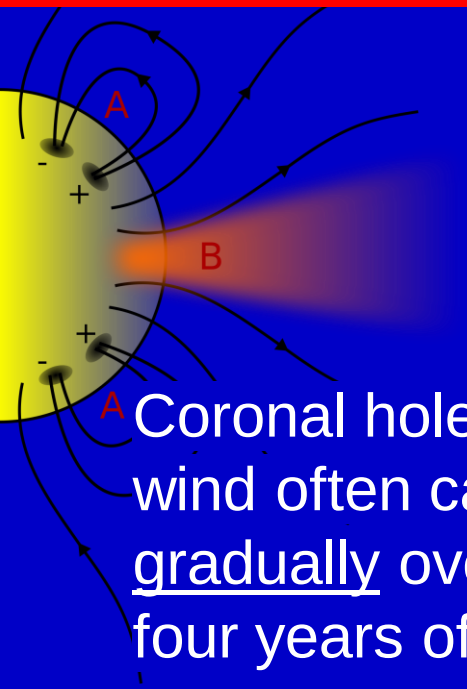
Solar Cycle 25 - Solar Hemispheric SSNs



https://solen.info/solar/images/cycle24.png

Coronal Hole High Speed Streams

Unlike the closed magnetic fields of sunspots, the open magnetic fields of coronal holes allow the corona's magnetized plasma to escape into interplanetary space



Coronal hole high speed streams are the most frequent source of minor geomagnetic storms throughout the solar cycle but most frequently during the declining four years of each solar cycle

Coronal hole high speed streams interact with the slow solar wind often causing minor geomagnetic storms that develop gradually over several hours especially during the declining four years of each solar cycle

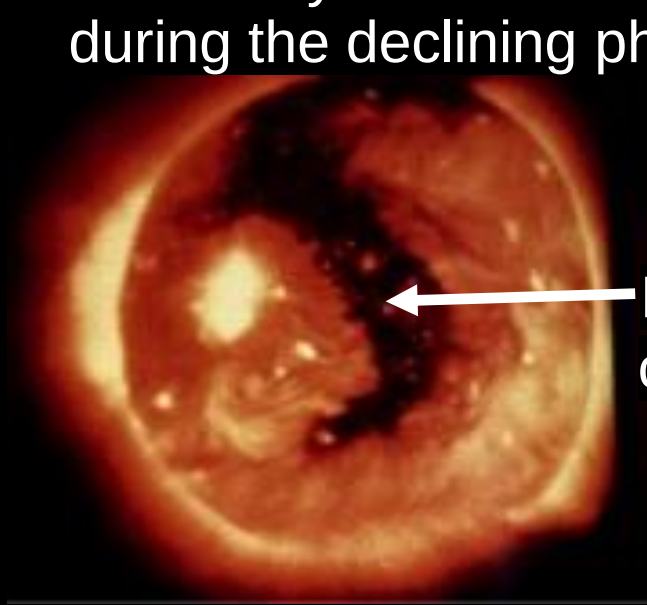
Conversely, fast CMEs originating in active regions sometimes cause strong geomagnetic storms that develop suddenly mostly during the four years of each solar cycle near solar maximum

Disturbed Geomagnetic Conditions
Caused by Coronal Hole High Speed Stream Effects

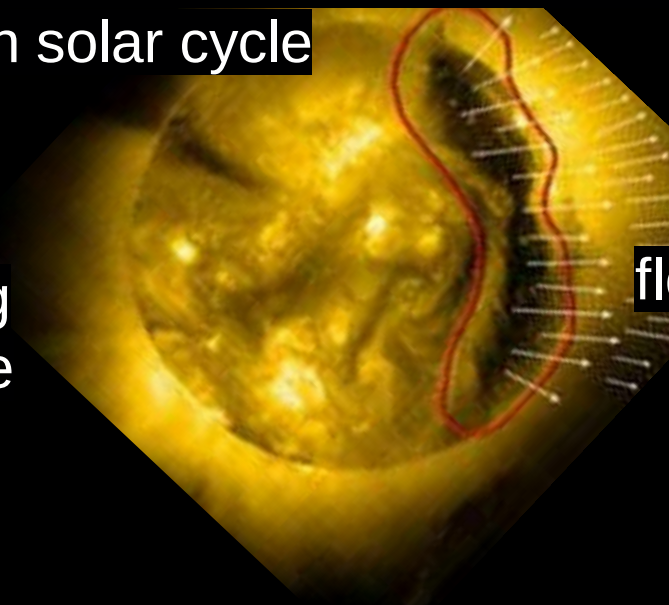
Open magnetic fields flowing from small coronal holes at low solar latitudes allow magnetized plasma to escape the Sun's gravity forming the ambient solar wind and the interplanetary magnetic field

Coronal hole high speed streams originating from large coronal holes when they are facing the Earth cause frequent unsettled to active geomagnetic disturbances and occasional minor geomagnetic storms

Disturbed geomagnetic activity and minor geomagnetic storms caused by coronal hole high speed streams occur most frequently during the declining phase of each solar cycle

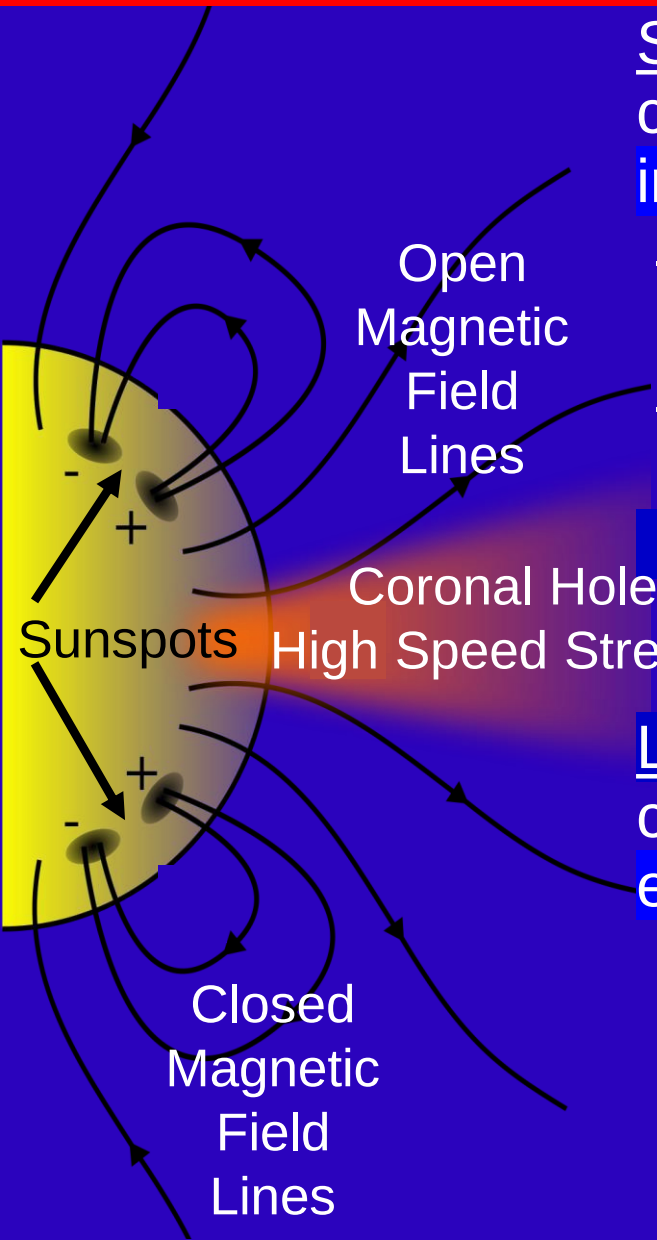


Very large Earth facing coronal hole



Open magnetic field lines flowing from a coronal hole

Short and Long Duration Minor Geomagnetic Storms



Short duration minor geomagnetic storms are caused by coronal hole high speed stream interactions with the ambient slow solar wind

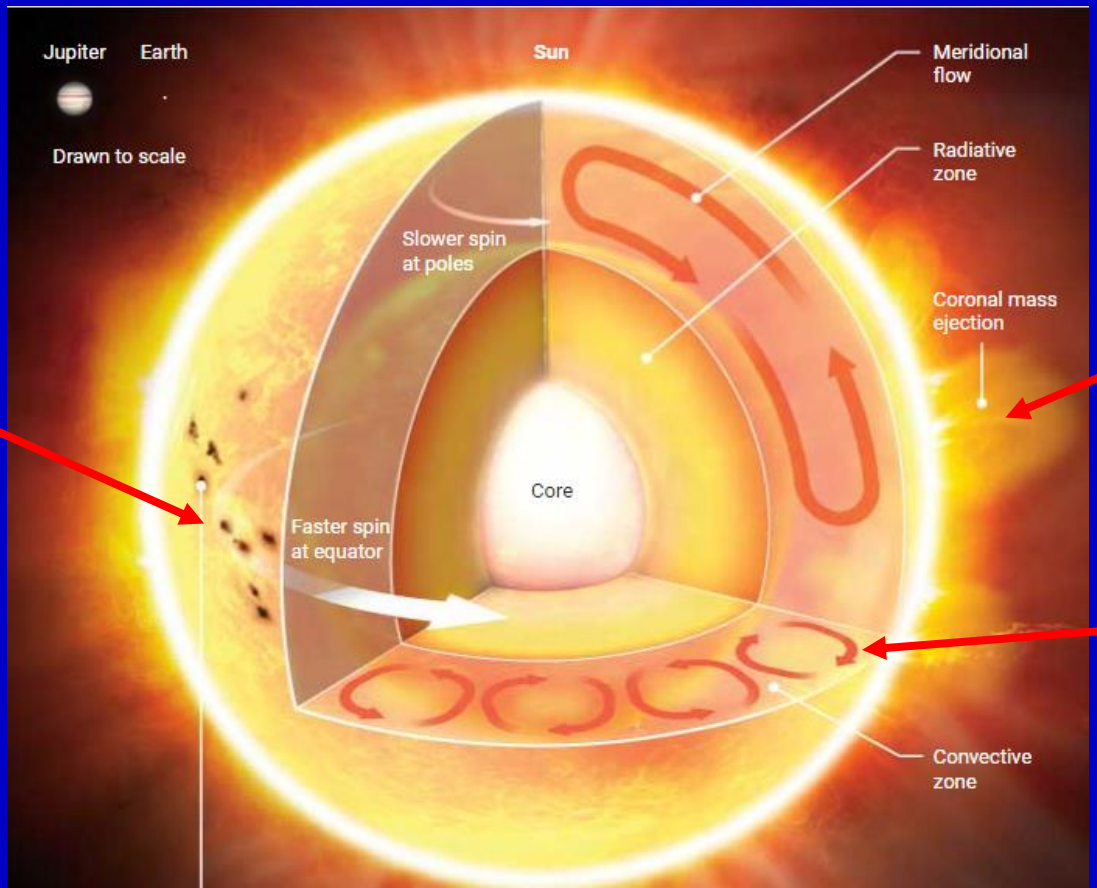
- do not significantly degrade HF propagation during the four years near solar maximum
- the most frequent cause of degraded HF propagation during the four years near solar minimum

Long duration minor geomagnetic storms are caused by geoeffective fast coronal mass ejections

- do not significantly degrade HF propagation during the four years near solar maximum
- occur about twice as frequently during the declining years of each solar cycle

The Sun's Twisting Magnetic Field Produces Active Regions and their Sunspots, Solar Flares and Coronal Mass Ejections

Differential rotation in the convective zone stretches, twists, tangles and strengthens the powerful submerged magnetic field which produces sunspots, solar flares and coronal mass ejections



Sunspots

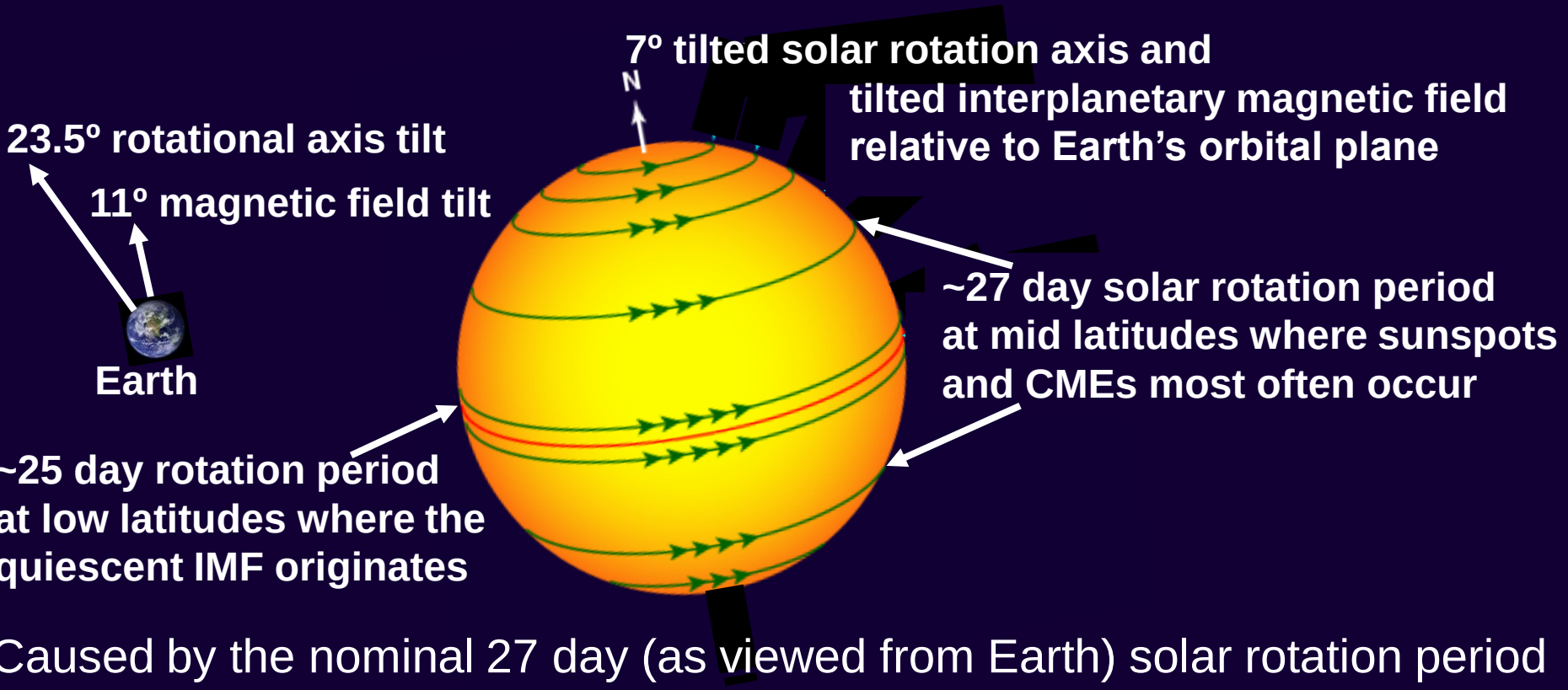
Coronal Mass Ejection

Convective zone

27 Day Recurrence of Large Active Sunspots and Coronal Mass Ejections (CMEs)

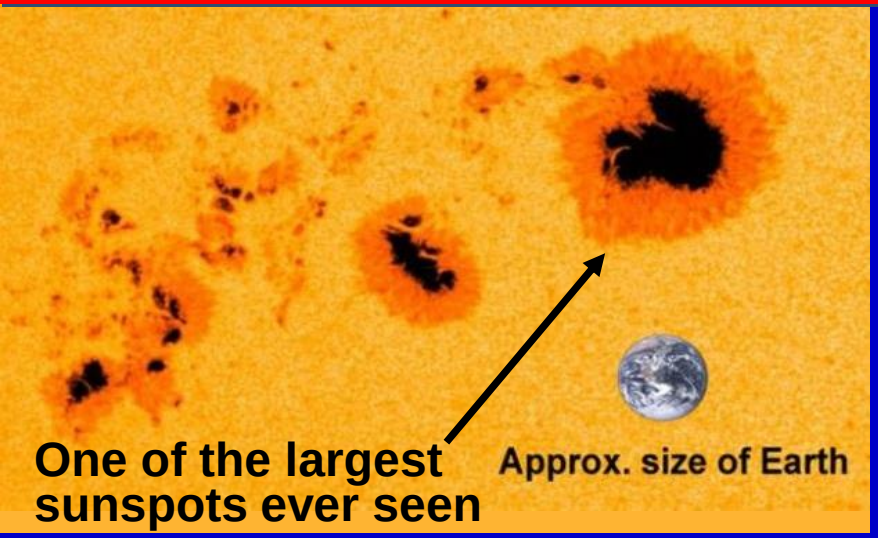
Enhanced HF propagation repeats about every 27 days as large sunspots rise on the east solar limb and set on the west limb

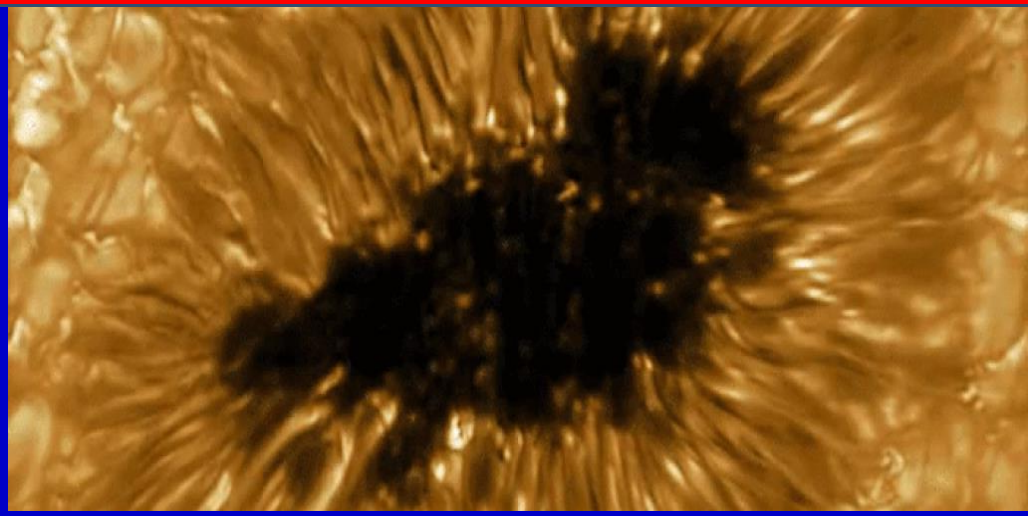
Geomagnetic disturbances repeat about every 27 days when large active sunspots are +/- 30º latitude from the central meridian



Caused by the nominal 27 day (as viewed from Earth) solar rotation period at latitudes where sunspots and coronal mass ejections most often appear

More Frequent, More Energetic Active Regions Produce Many More Sunspots, Solar Flares and Coronal Mass Ejections





An active region containing many large sunspots rotates across the visible disk

During solar maximum active regions radiate:

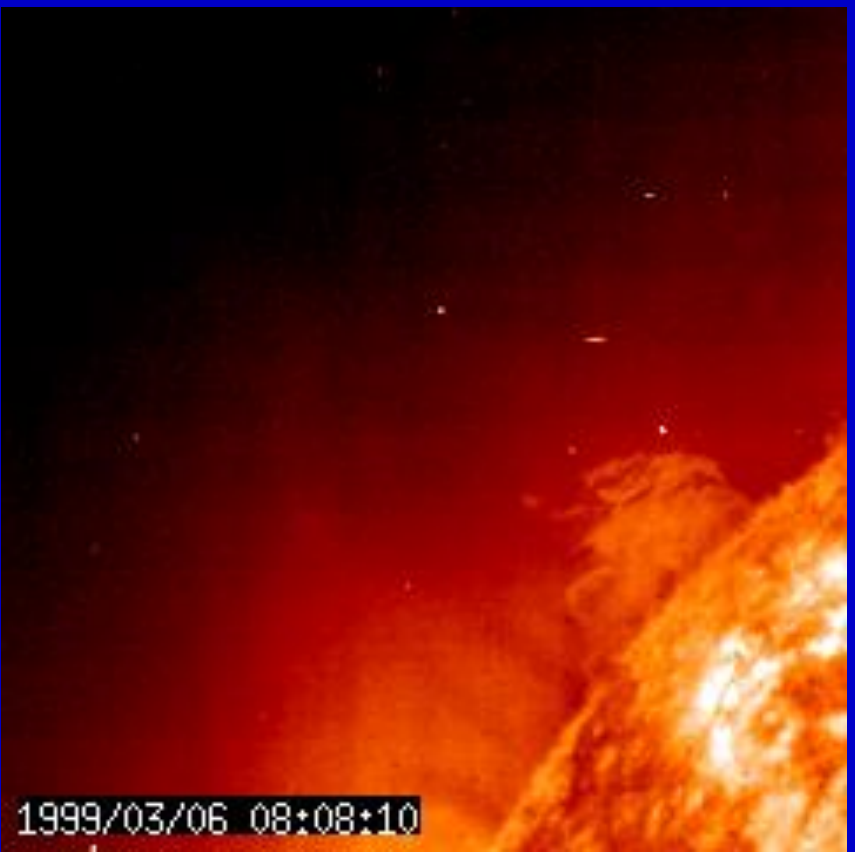
- Stronger ionizing extreme ultraviolet radiation enhancing HF propagation on upper HF bands
- Highly energetic magnetized plasma from fast interplanetary CMEs causing more frequent strong geomagnetic storms
- Highly energetic hard x-rays from solar flares cause more frequent daytime radio blackouts

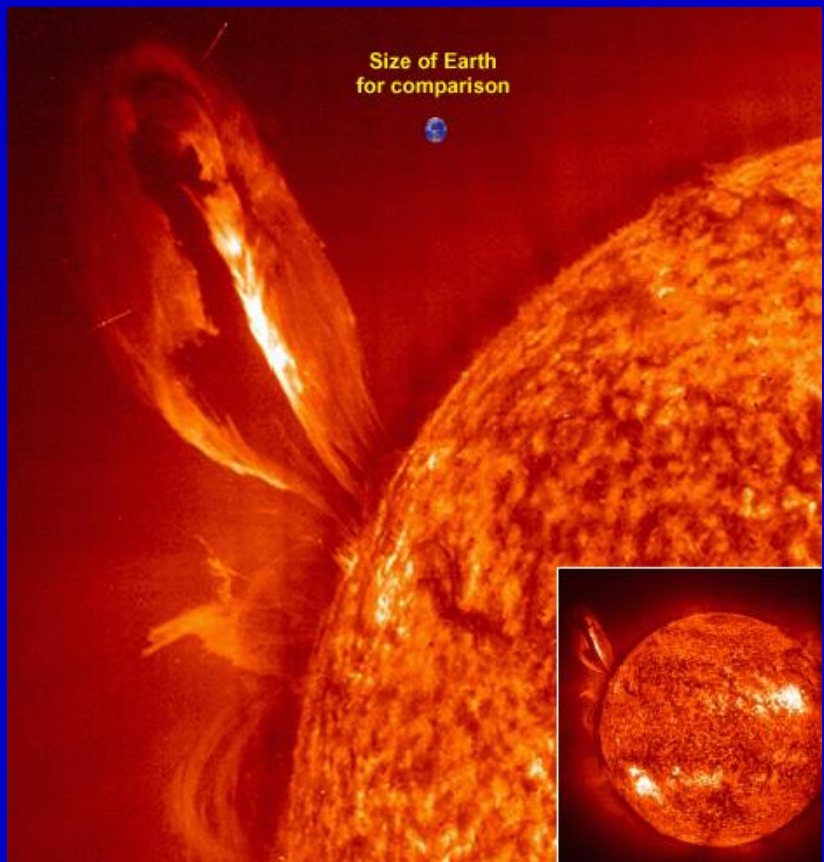
Solar Flares and their Associated CMEs

Massive explosions of X-rays and plasma from active regions

95% of solar flares occur when the solar flux index is 90 or greater during the four years of greatest solar activity near solar maximum

In just a few minutes coronal mass ejections often associated with solar flares can release as much as ten billion tons of magnetized plasma travelling to the planets from 700 to more than 1000 km/second





Daytime HF Radio Blackouts Caused by X-Class and M-Class Solar Flares Mostly During the Years Near Solar Maximum

Radio blackouts affect *only* propagation crossing daylight regions

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-blackout conditions an hour or two after the onset of a radio blackout

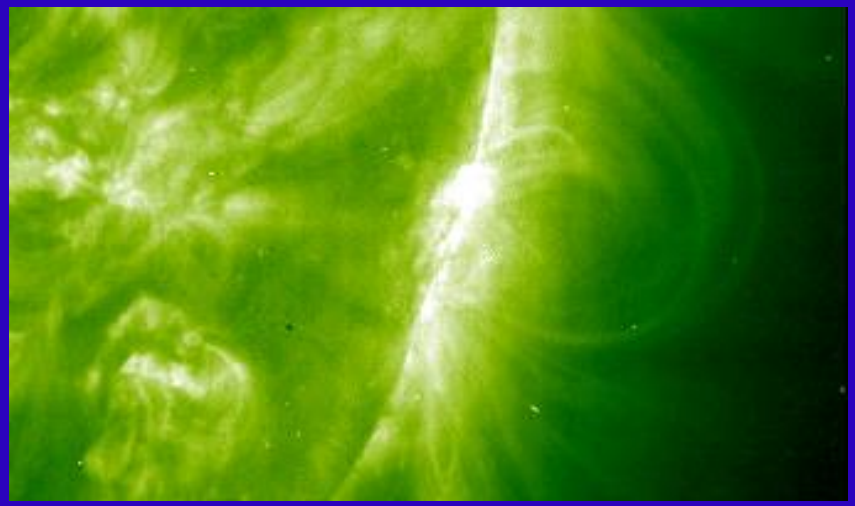
Higher frequency ha, bands return to near pre-blackout level more quickly than lower frequencies

Powerful X-Class Solar Flares
severely impact daytime HF ionospheric propagation

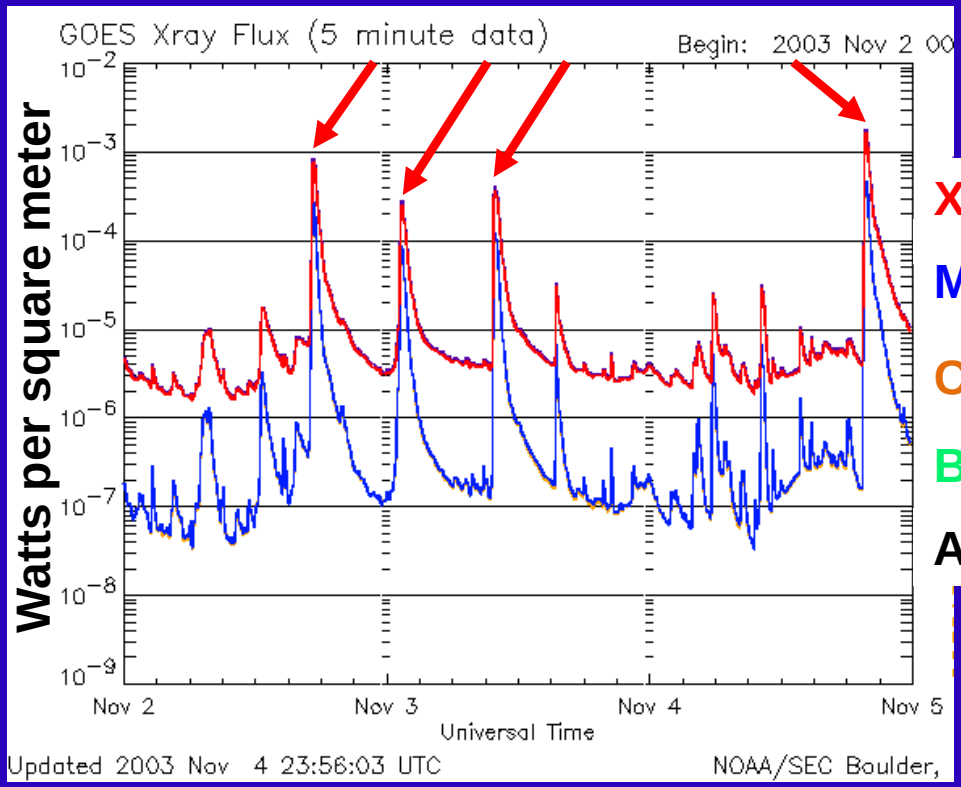
X10-Class – extreme flares produce long duration hemisphere-wide radio blackouts

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

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



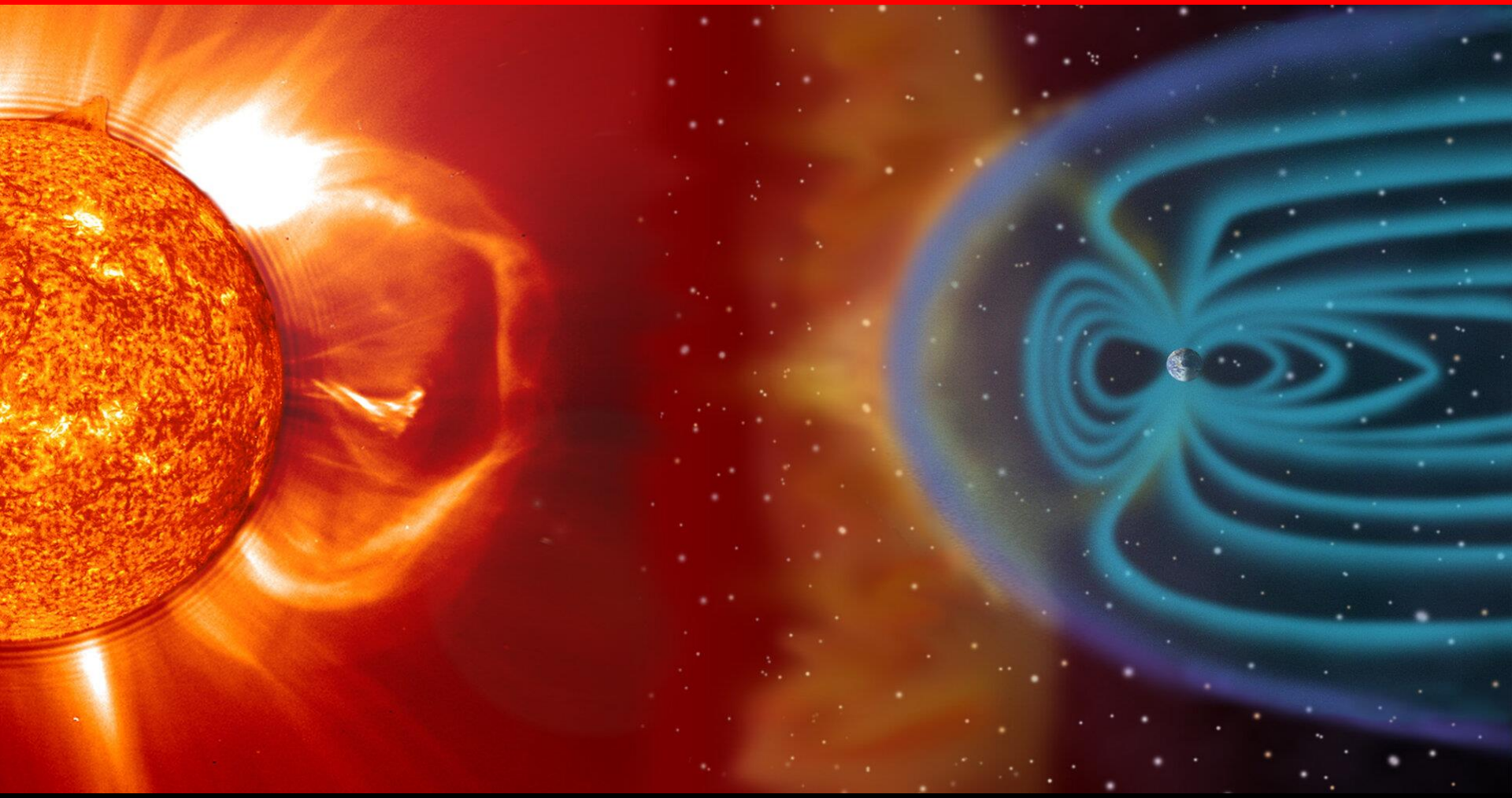
X28 flare -- the largest ever recorded erupts on November 4, 2003



Four X-class flares
2-5 November 2003

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

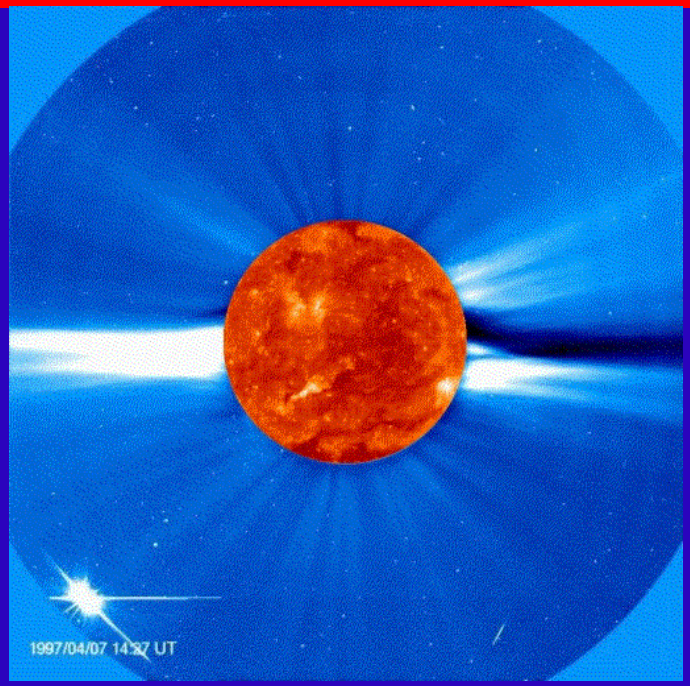
More Frequent Fast Coronal Mass Ejections Through 2026



Fast interplanetary CMEs cause more frequent and longer lasting moderate and severe 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 HF propagation disturbances caused by geomagnetic storms



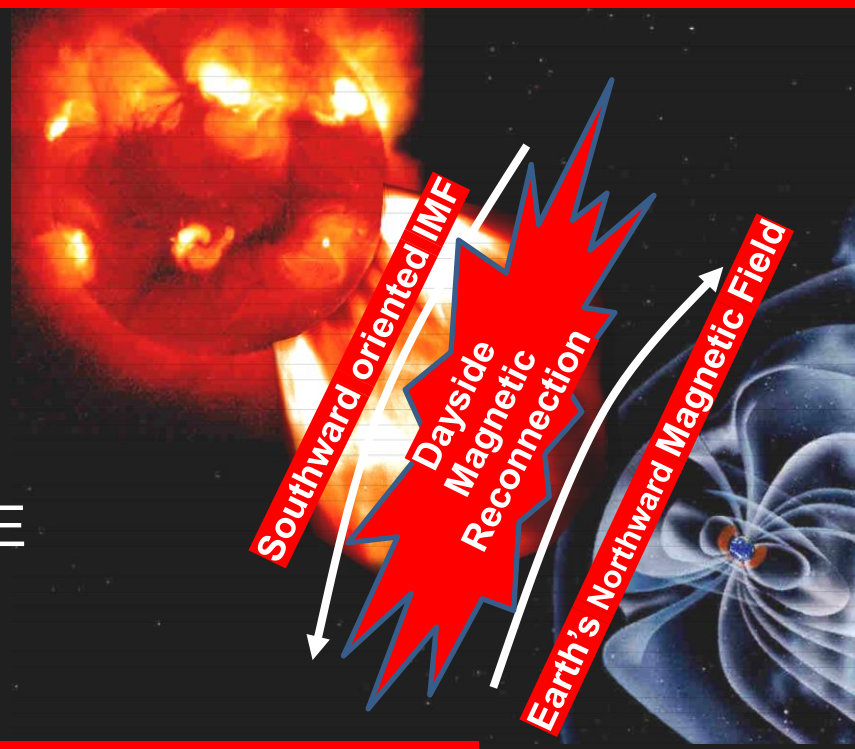
Fast CME impacts are greatly magnified when the interplanetary magnetic field (IMF) persists in a southward orientation -- opposite to Earth's magnetic field -- for more than a few hours

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 occur more frequently during the seven most active years of the solar cycle

The most severe geomagnetic storms occur most often:

- when they occur within a few weeks of the equinoxes on Earth, and
- when directed toward the Earth from <30º solar latitude, and
- when directed from +/- 30º longitude from the Sun's central meridian

High Level Overview of HF Propagation Through 2026

- Solar maximum propagation conditions began in January 2023 and continue through 2026
- 10, 12 and especially 15 and 17 meter worldwide propagation persists later into the night through 2026
- 10 and 12 meter DX propagation continues through 2026
- 20, 30 and 40 meter DX propagation continues throughout the night through 2026
- Geomagnetic disturbances gradually become more frequent as 2026 approaches
- Sunspot activity begins to steadily decline after 2026 until solar minimum in about 2031

What HF Bands Should I use for DXing Through 2026?

- Each band has its unique advantages and disadvantages
- 17, 15, 12 and 10 meters provide reliable daytime worldwide propagation from September through May
- 20 meters provides reliable daytime and nighttime worldwide propagation throughout the year
  - But not during midday from June through August
- 40 meters provides reliable nighttime worldwide propagation throughout the year
- 80 meters often provides good nighttime worldwide propagation from October through April

How Solar Maximum Affects 12 and 10 Meter Worldwide Propagation Through 2026

- Worldwide propagation improved dramatically since early 2023
  - almost every day from mid-September through late April
  - excellent propagation to Europe from sunrise to early afternoon
  - excellent propagation to Japan and Asia after 2130Z sometimes continuing for as long as three or four hours
- Worldwide propagation between northern hemisphere locations will continue sporadically during most days from May through mid-September
  - Sporadic-E is the dominant May to mid-August propagation
- Excellent worldwide propagation is likely to continue through 2026

How Solar Maximum Affects 17 and 15 Meter Worldwide Propagation Through 2026

- Worldwide propagation improved dramatically since 2022
  - almost every day from September through May
  - Excellent propagation to Europe from before sunrise to mid-afternoon
  - excellent propagation to Japan and Asia after 2130Z sometimes for as long as four hours or more
- Worldwide propagation between northern hemisphere locations begins later and is shorter in duration from June to August
  - Sporadic-E is sometimes the dominant 15 meter propagation mode from mid-May to mid-August

How Solar Maximum Affects 20 Meter Worldwide Propagation Through 2026

- Nighttime propagation improved dramatically since January 2023
  - almost 24 hour per day worldwide propagation
    - but not during summer mid-day hours
  - excellent nighttime propagation to Europe from 0700-0900Z
  - excellent propagation to Europe resumes before our sunrise
  - DX activity switches to 17, 15, 12 and 10 meters shortly after our sunrise
- Propagation to Japan and Asia is strongest from Asian sunrise throughout the night until several hours after our sunrise
- Midday 20 meter DX propagation is always very poor from June through August

How Solar Maximum Affects 40 and 30 Meter Worldwide Propagation Through 2026

- Worldwide propagation throughout the night is now more reliable and more long lasting since 2022
  - propagation to Europe starts about an hour before sunset
  - continues throughout the night until a few hours after European sunrise when Europeans shift to higher bands
  - the best European propagation and activity is often around European sunrise (0600-0800Z)
- Mid-afternoon propagation to Europe is weaker since 2022
  - most of DX activity is still on the higher bands
- Propagation from the east coast to Japan and Asia is more reliable since 2022 starting at sunset in Japan (0800Z) until about 30 minutes after our sunrise

How Solar Maximum Affects 160 and 80 Meter Worldwide Propagation Through 2026

- 80 meter DX propagation is shorter in duration since 2022
  - weak and unreliable DX propagation begins at sunset
  - better European propagation starts a few hours after sunset
  - the best European activity is often just before their sunrise
    - continuing until just after European sunrise when most Europeans shift their operations to higher bands
- 160 meter DX propagation is very unreliable since 2022
  - weak unreliable DX propagation begins after sunset
  - propagation to Europe sometimes improves around midnight for just a few hours or much less
- 160 & 80 meter DX propagation will steadily improve after 2026

Nowcasting using the Reverse Beacon Network

80 Meters European CW CQs heard in North America 0500Z

630m 160m 80m 60m 40m 30m 20m 17m 15m 12m 10m 6m 4m 2m

cw rtty psk31 psk63

	● 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

Nowcasting using PSK Reporter

20 Meters Worldwide FT8 heard in North America 2200Z