HF Propagation Knowledge to Improve Your DXing During Solar Maximum

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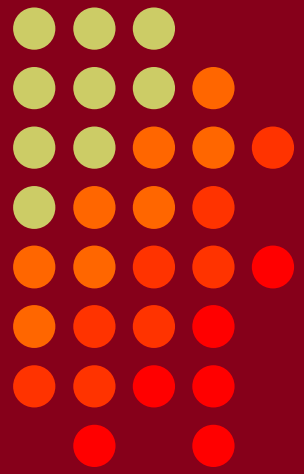


Experience the Wonders of Solar Cycle 25's Solar Maximum

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

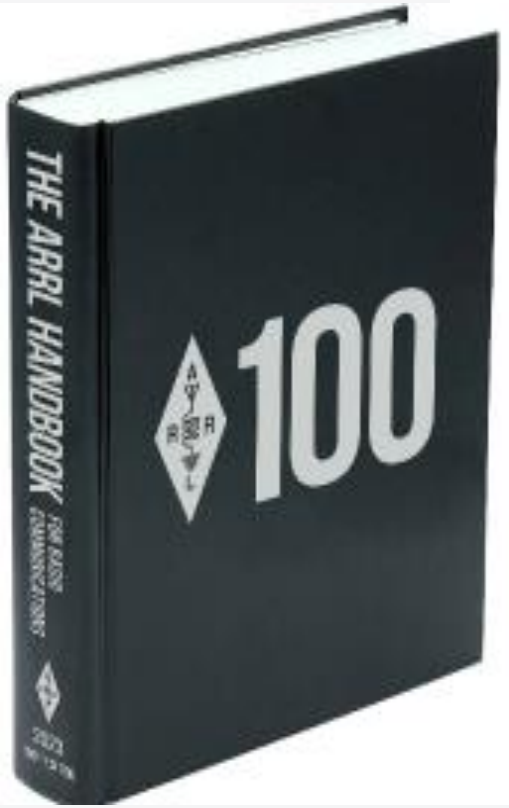
CYCLE 25

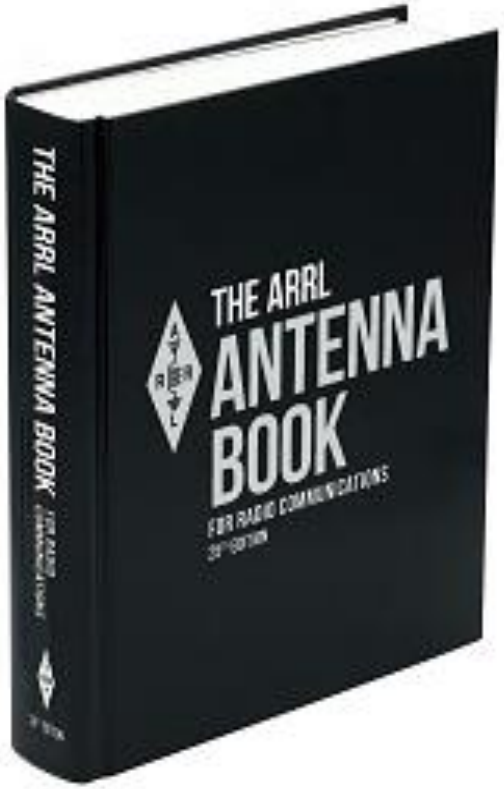
Frank Donovan W3LPL

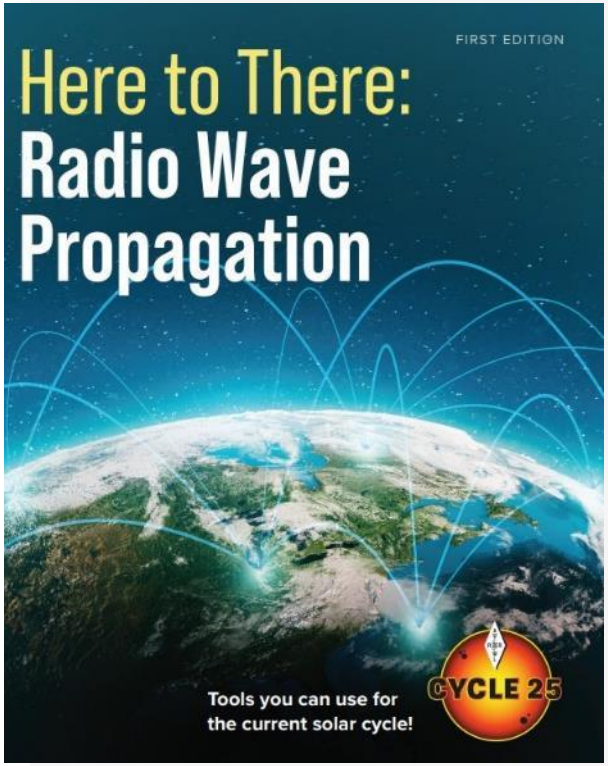
May 2023 QST

arrl.org/qst

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







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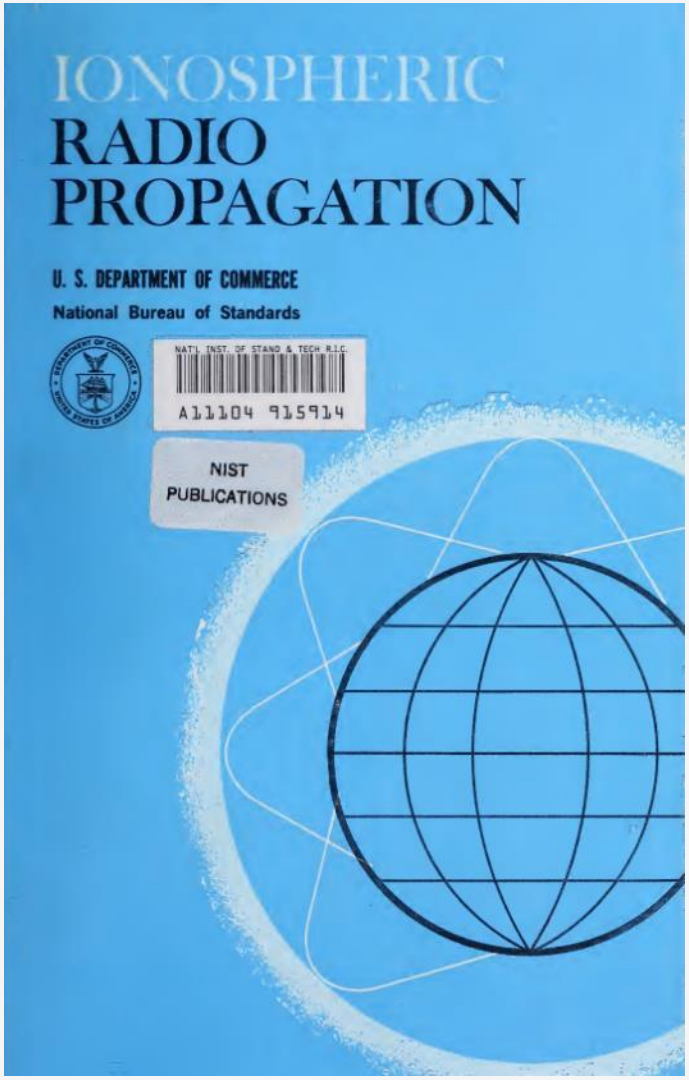
An Excellent Free Technical Reference for Scientifically Inclined Amateurs



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

All HF Propagation Originates on the Sun

Magnetic Field: creates the corona and IMF
Corona: Superheated magnetized plasma
Active Regions: sunspots, solar flares, CMEs
Sunspots: concentrated closed magnetic fields
Solar Cycle: rising, maximum, declining, minimum
Solar Wind: megatons/sec of magnetized plasma
Coronal Holes: source of high speed solar wind
CMEs: powerful explosions of magnetized plasma
Solar Flares: intense X-ray and proton radiation

Key Features of the Sun-Earth System

every HF contester 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 and disturbances from solar flares, hard x-rays, energetic protons and CMEs originate in active regions

Solar Cycles usually 11 years, as short as 9 years, as long as 14 years. Some cycles have a long lasting and more energetic solar maximum. Some cycles have a long lasting and less energetic solar minimum.

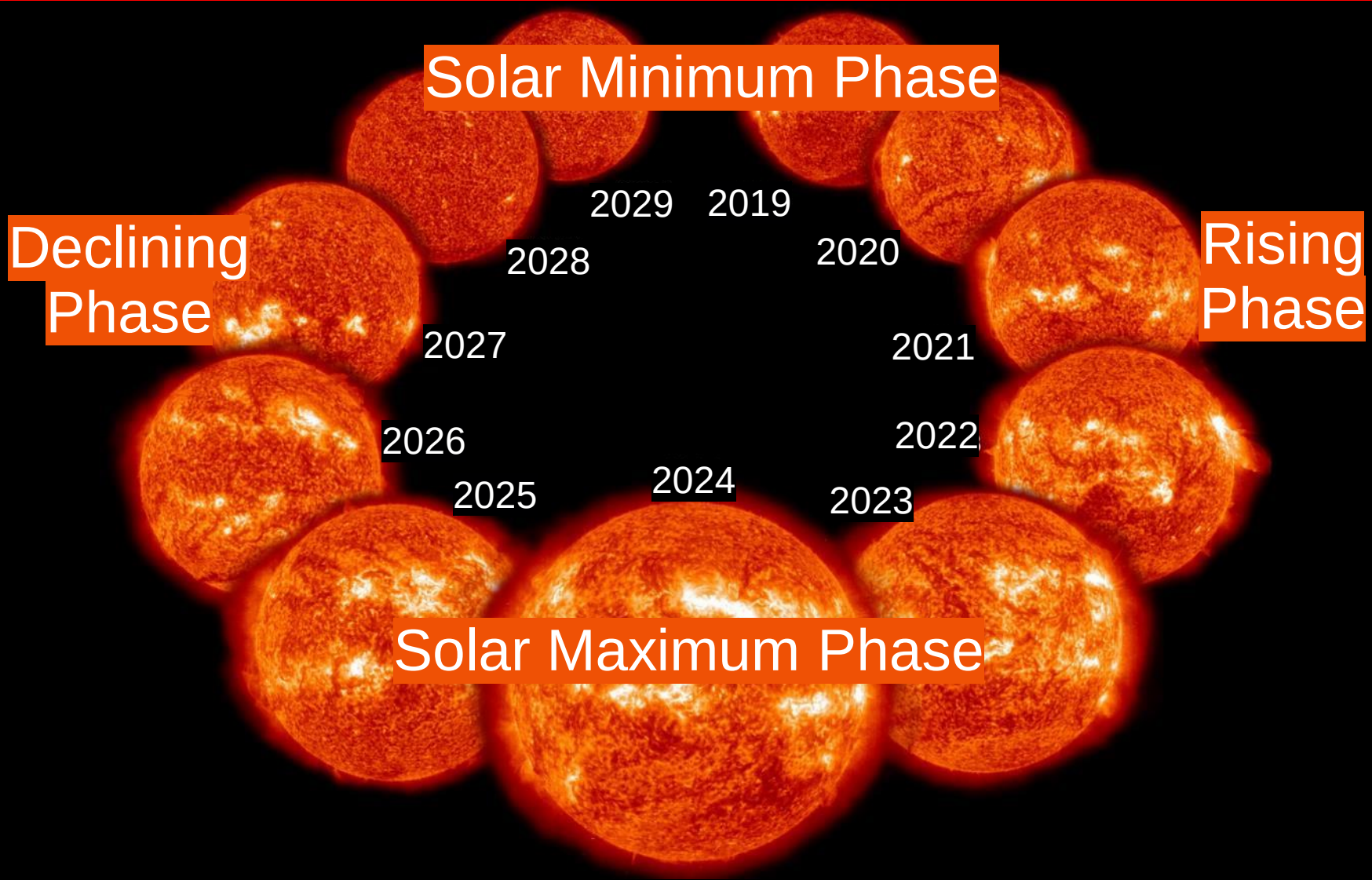
Ionizing Radiation Ten times more ionizing extreme ultraviolet radiation during solar maximum improves HF propagation especially during fall, winter and spring. Highly energetic x-rays from solar flares can suddenly black out daytime HF propagation for up to two hours with no warning

Geomagnetic Disturbances HF propagation is often degraded by the enhanced hypersonic flow of magnetized plasma in the solar wind

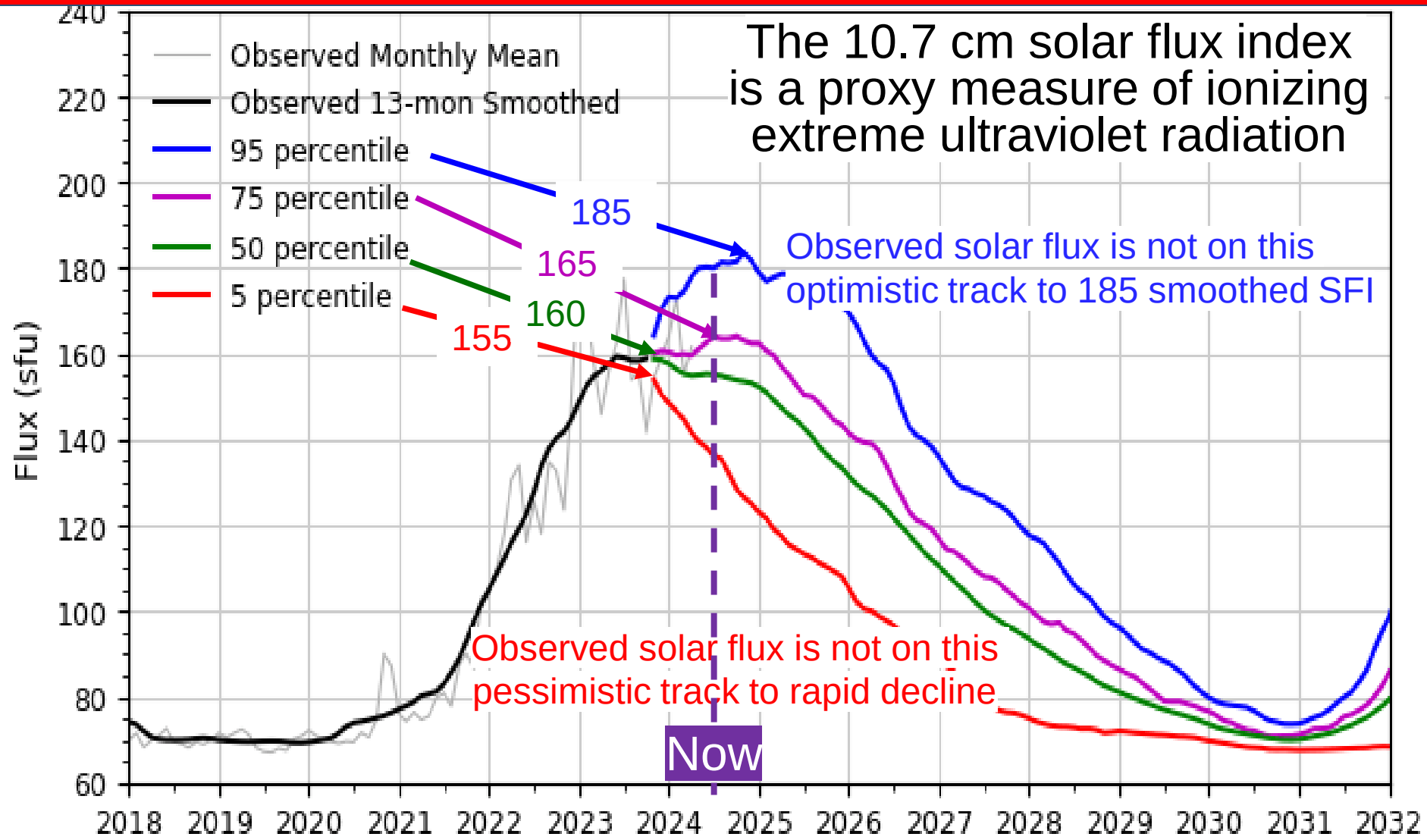
27 Day Solar Rotation 27 day periods of enhancement and disturbance

Seasonal Variability Earth's 23.5º tilted axis increases ionizing EUV radiation intensity at mid and high latitudes during summer and decreases it during winter. Earth's tilted axis also reduces the intensity and frequency of disturbed HF propagation during summer and winter

Enhanced Ionizing Extreme Ultraviolet Radiation Through 2026 Produces Greatly Improved 40 to 10 Meter Propagation



Solar Cycle 25 *Solar Flux Index* Forecast
NASA Marshall Space Flight Center – June 6, 2024

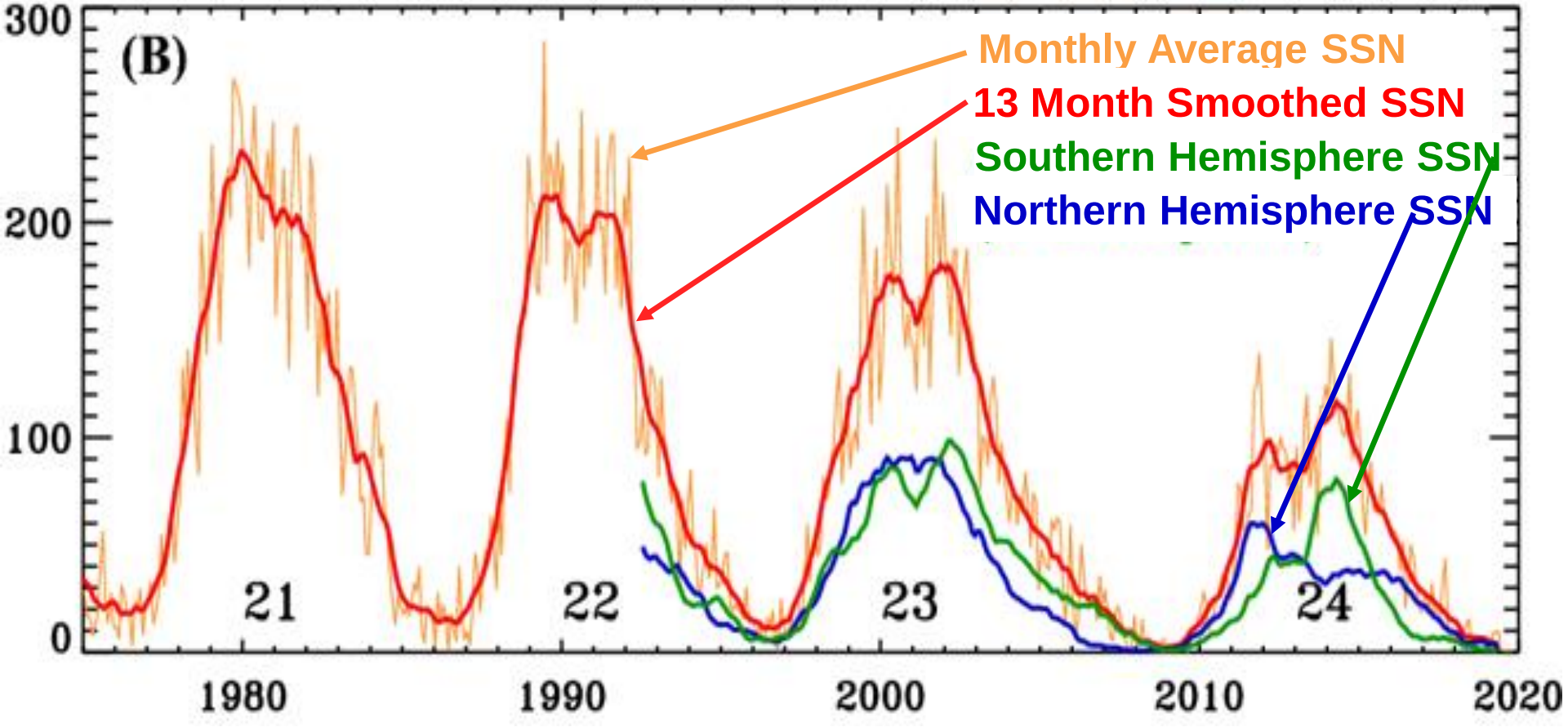


www.nasa.gov/msfcsolar

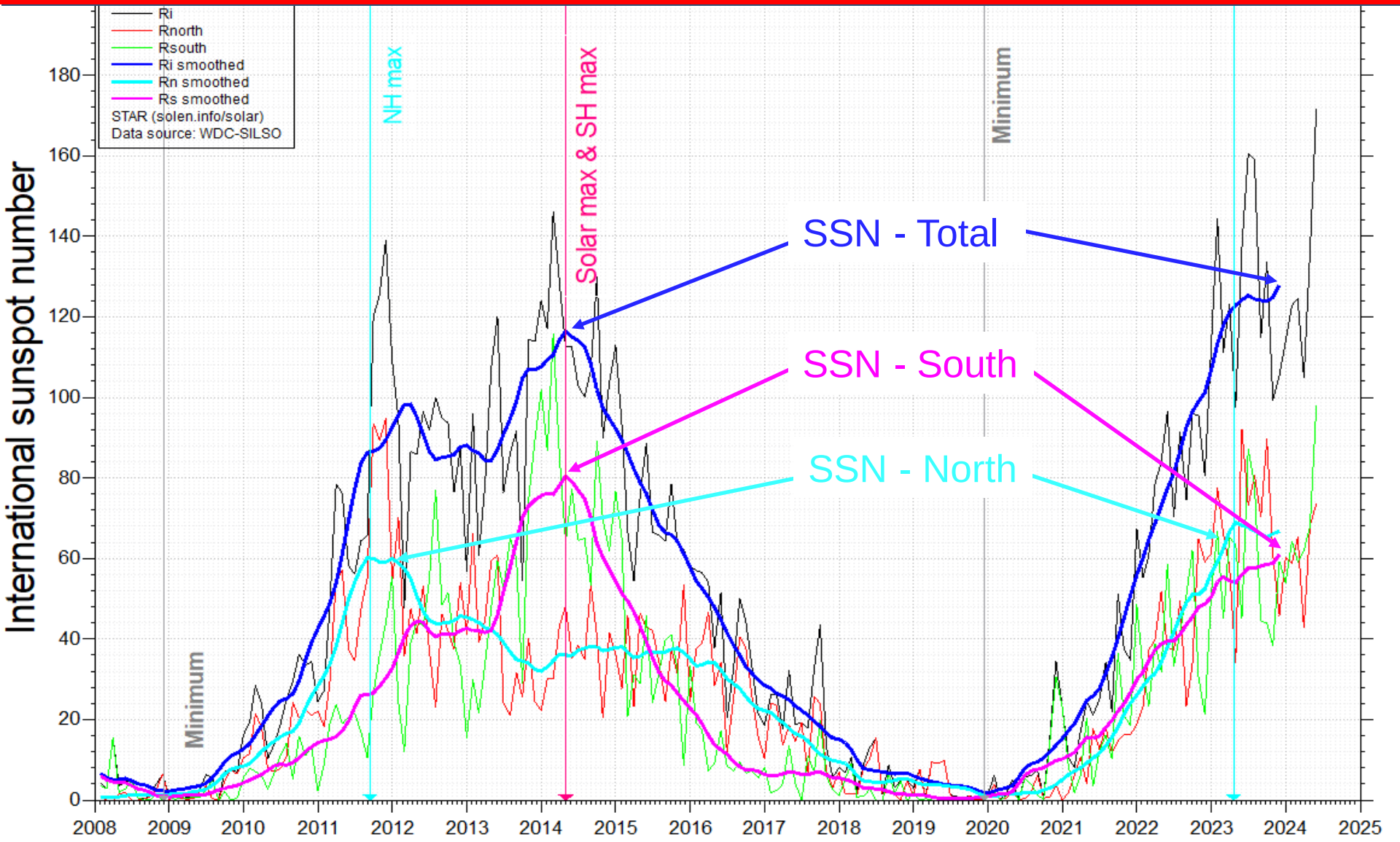
The Sun's Northern and Southern Hemisphere Solar Cycles Can be Offset by Up to Two Years

Solar cycle duration varies from 8 to more than 14 years

Propagation models use the 13 month smoothed SSN

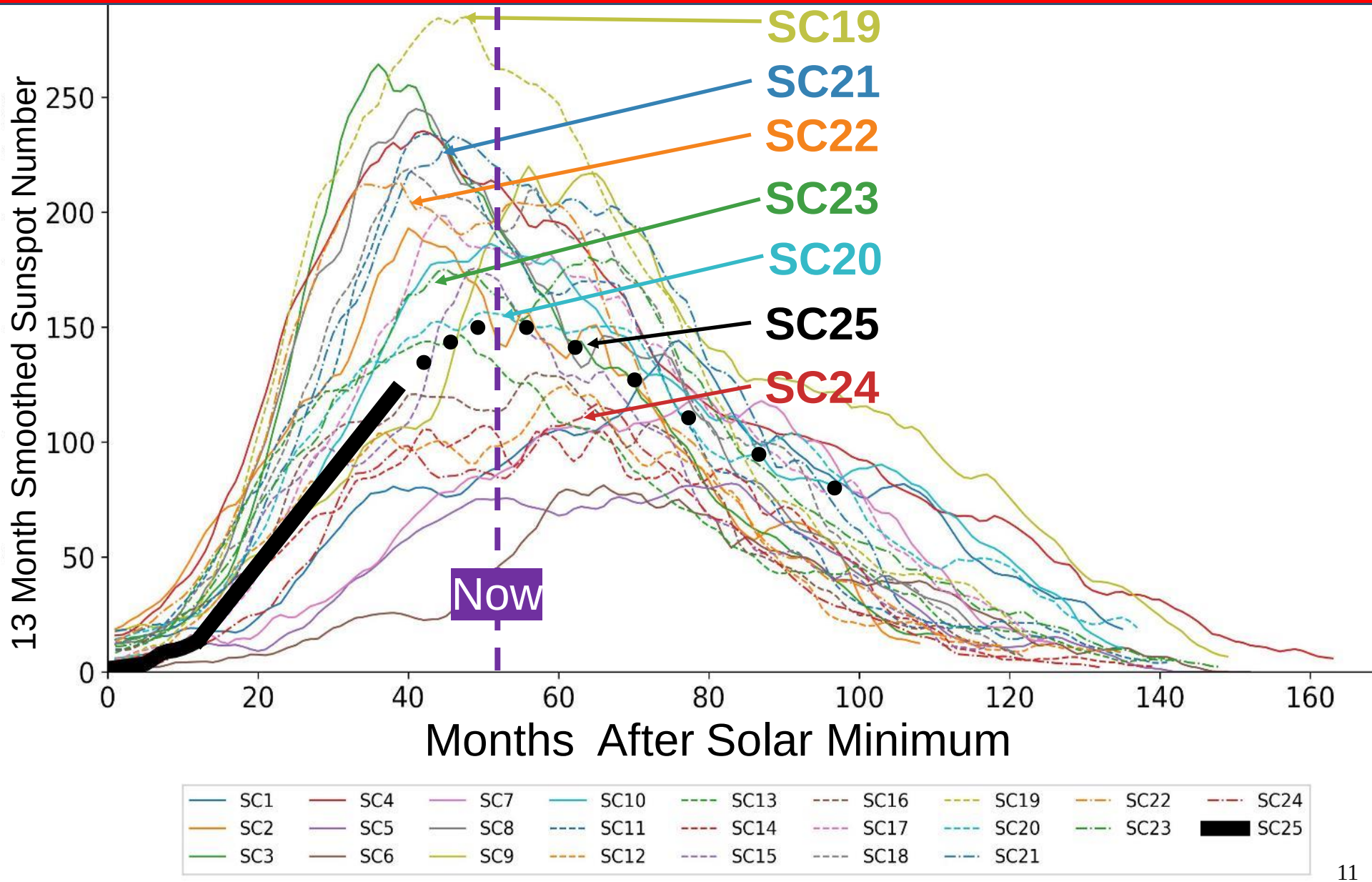


Solar Cycle 25 Progress vs Solar Cycle 24

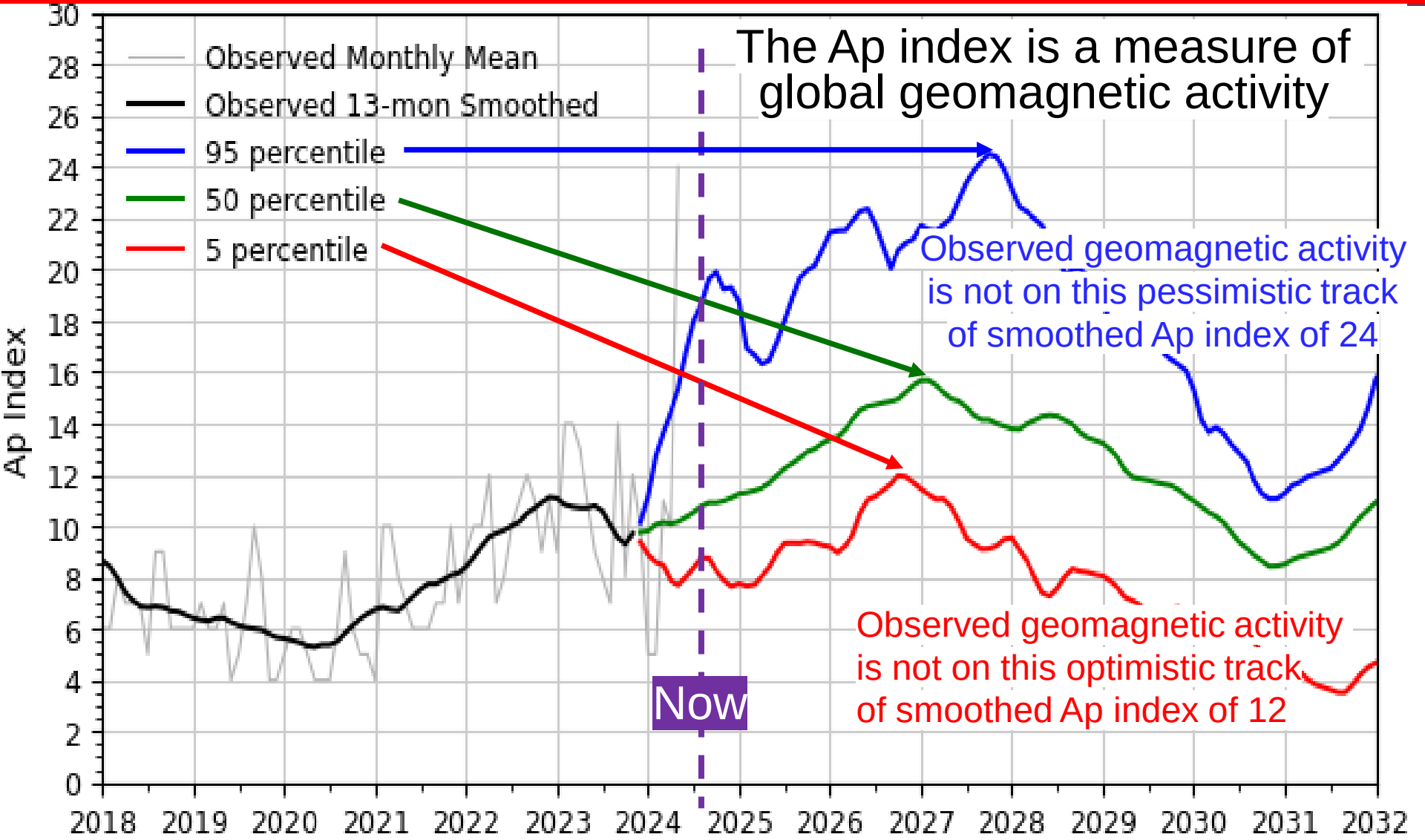


https://solen.info/solar/images/cycle24.png

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

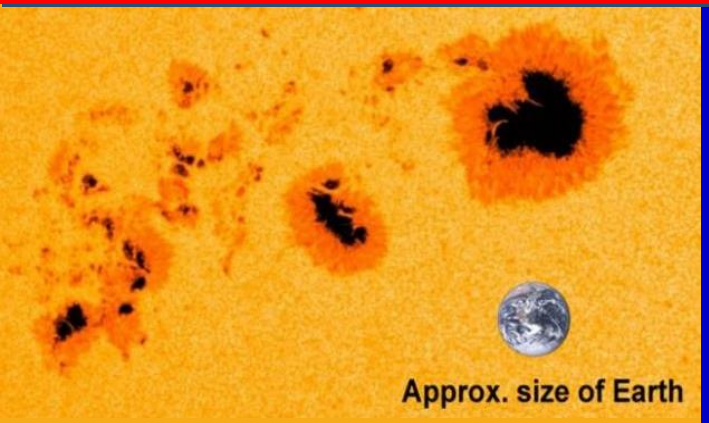


Solar Cycle 25 Geomagnetic Ap Index Forecast
NASA Marshall Space Flight Center – June 6, 2024

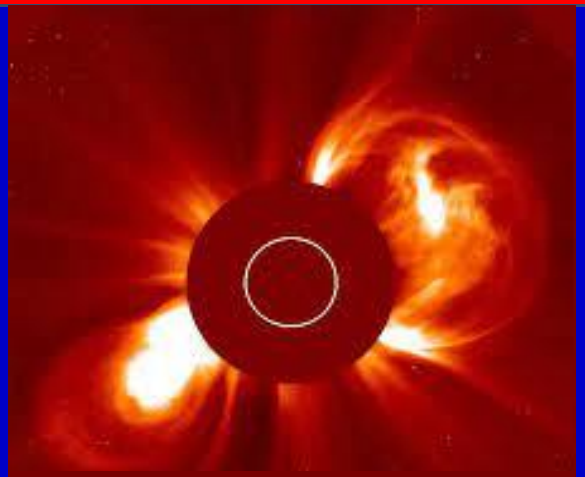


www.nasa.gov/msfcsolar

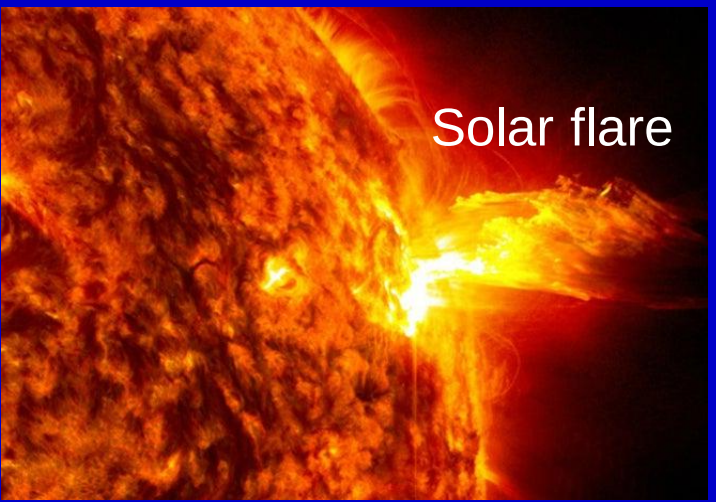
More Frequent, More Energetic Active Regions Produce Many More Sunspots, Solar Flares and Coronal Mass Ejections



One of the largest sunspots ever seen



Coronal mass ejection



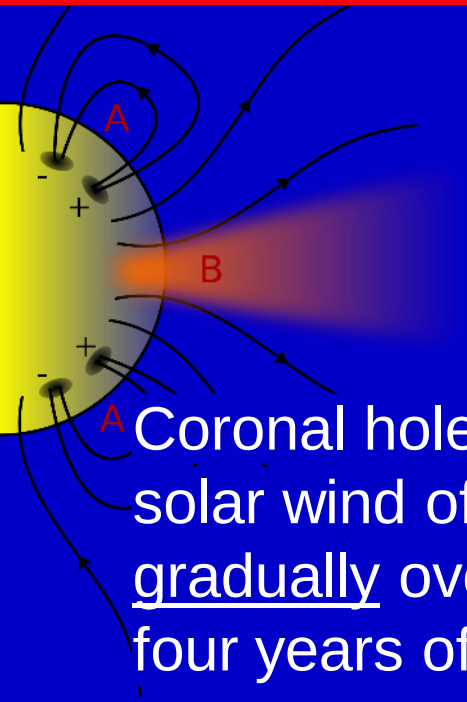
Solar flare

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

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 space forming the solar wind



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 ambient solar wind often causing minor geomagnetic storms that develop gradually over several hours most frequently during the declining four years of each solar cycle

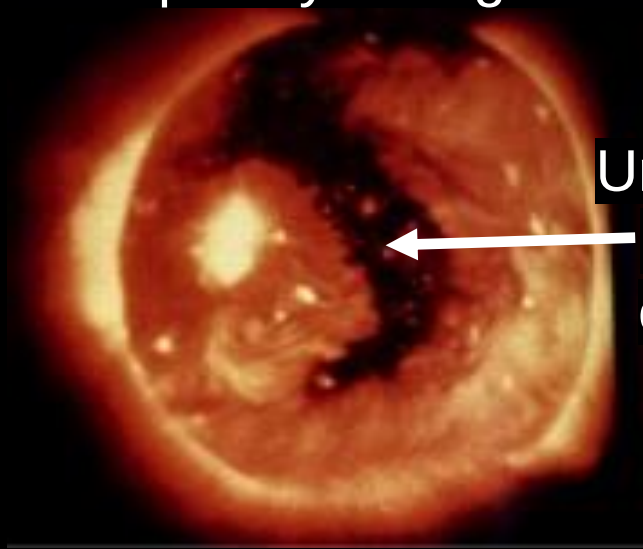
Conversely, fast CMEs originating in active regions sometimes cause strong and rare extreme geomagnetic storms that develop suddenly mostly during the four years near solar maximum

Disturbed Geomagnetic Conditions
Caused by Coronal Hole High Speed Stream Effects

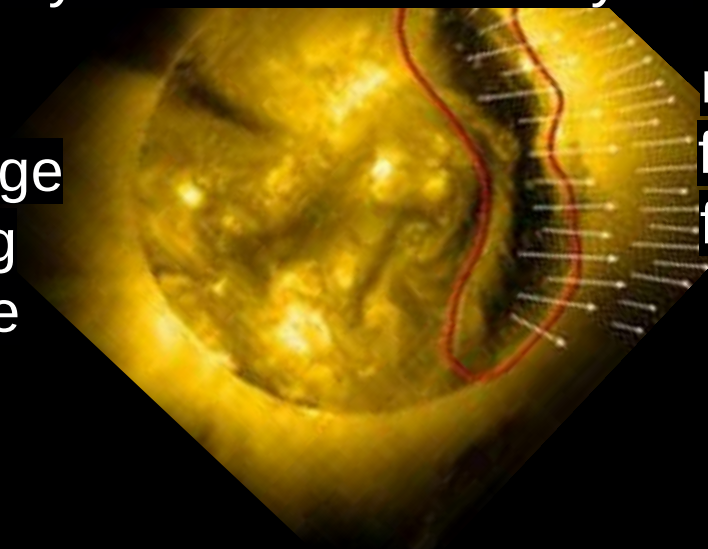
Open magnetic fields flowing from small coronal holes at low solar latitudes allow magnetized plasma to escape the Sun's gravity forming the ambient solar wind and the interplanetary magnetic field

Coronal hole high speed streams originating from large Earth facing low latitude coronal holes 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 stream effects occur most frequently during the declining four years of each solar cycle

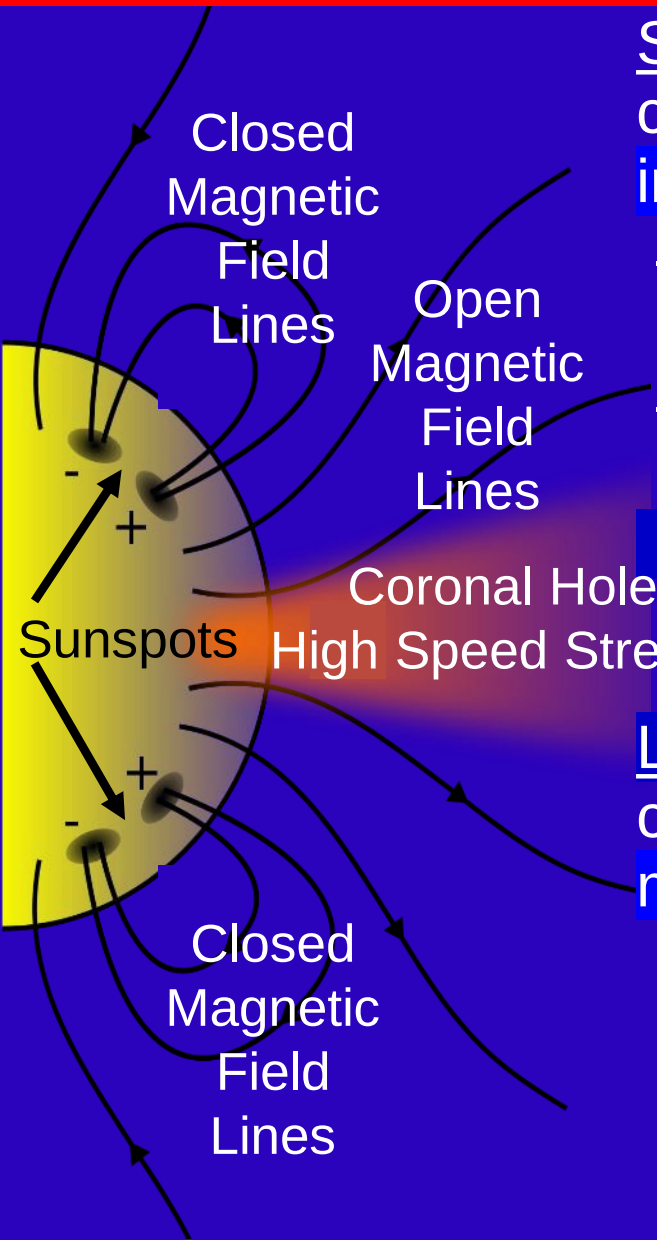


Unusually large Earth facing coronal hole



Open magnetic field lines flow from coronal holes

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

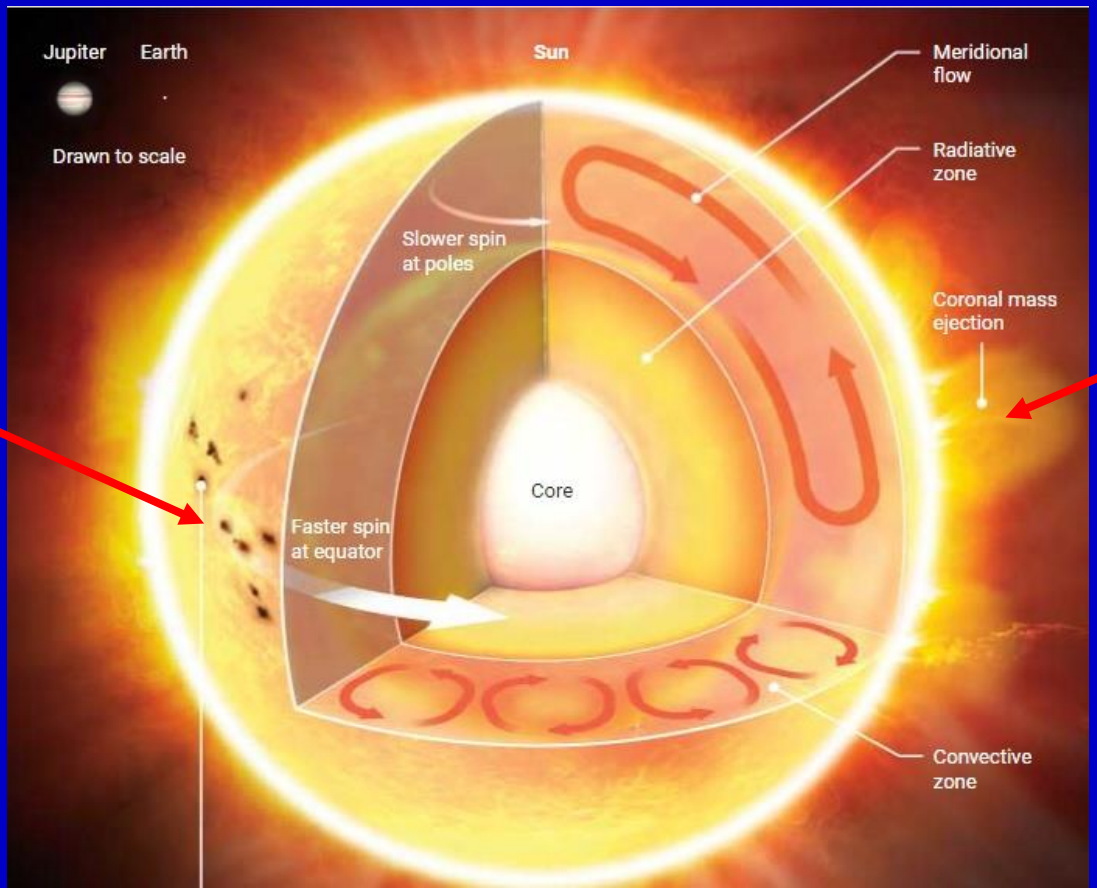
Long duration minor geomagnetic storms are caused by geoeffective interplanetary coronal mass ejections

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

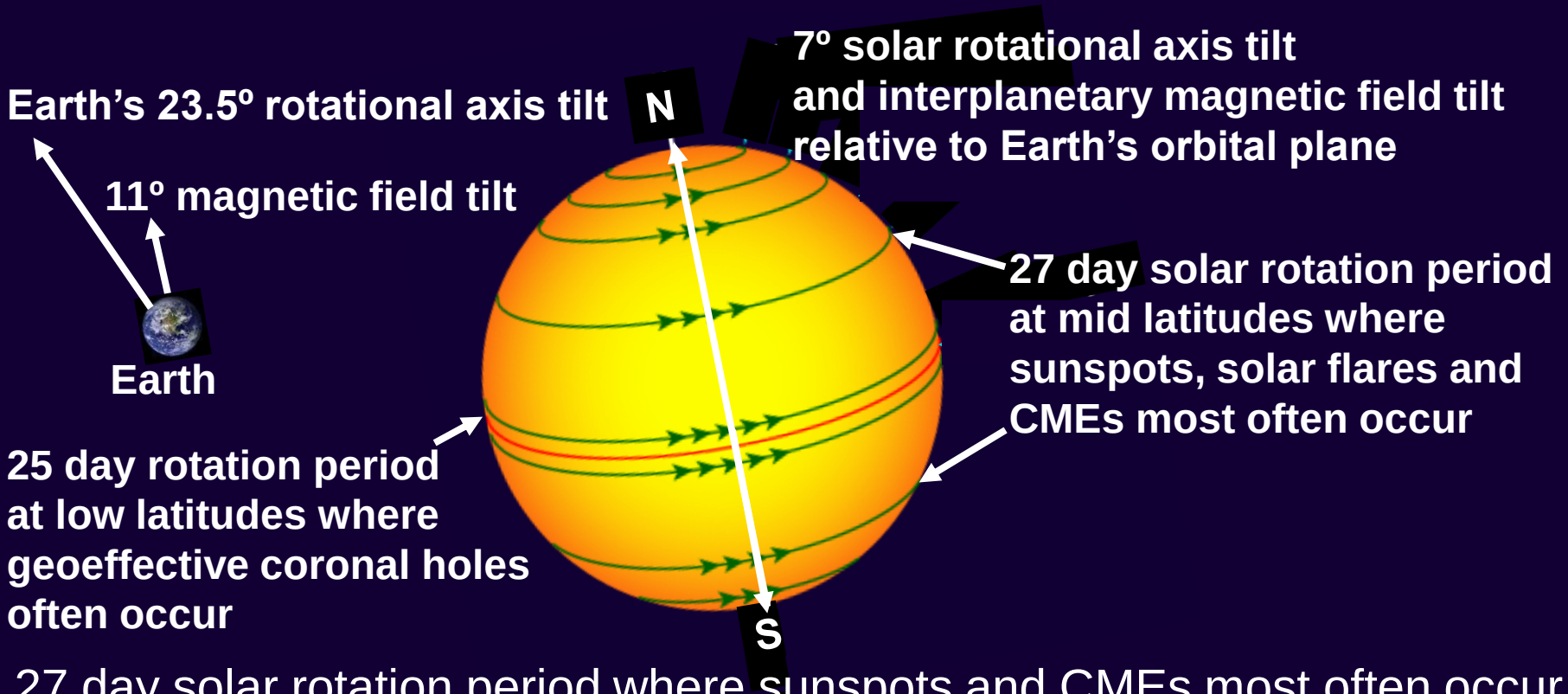


Coronal Mass Ejection

27 Day Recurrent Sunspots and 25 Day Recurrent Coronal Holes

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

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



27 day solar rotation period where sunspots and CMEs most often occur

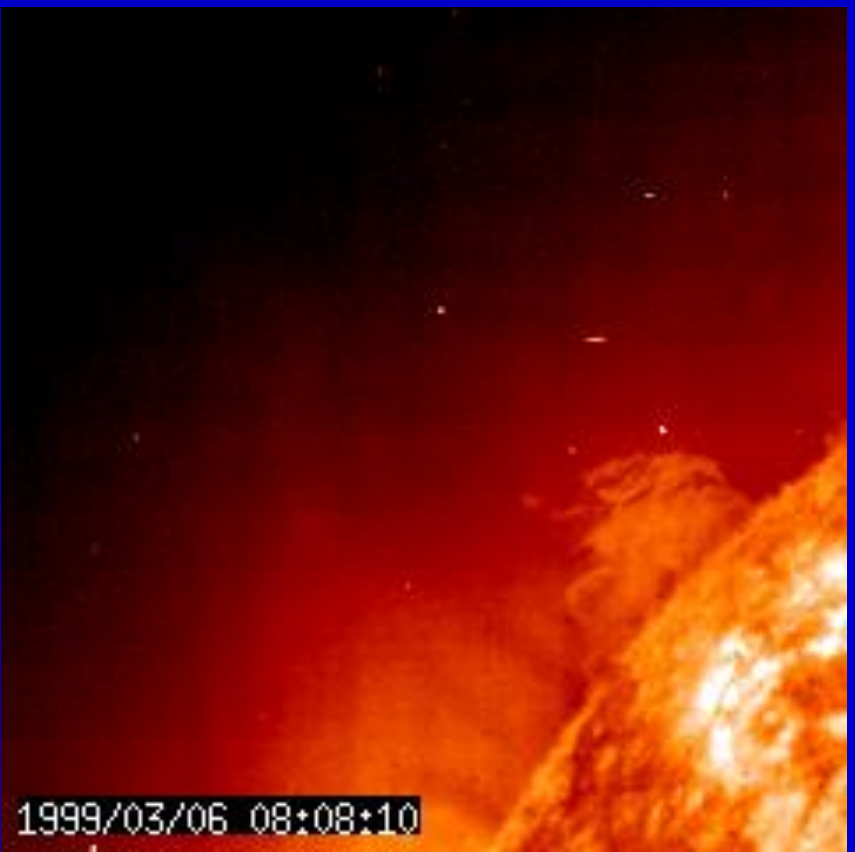
25 day solar rotation period where geoeffective coronal holes often occur

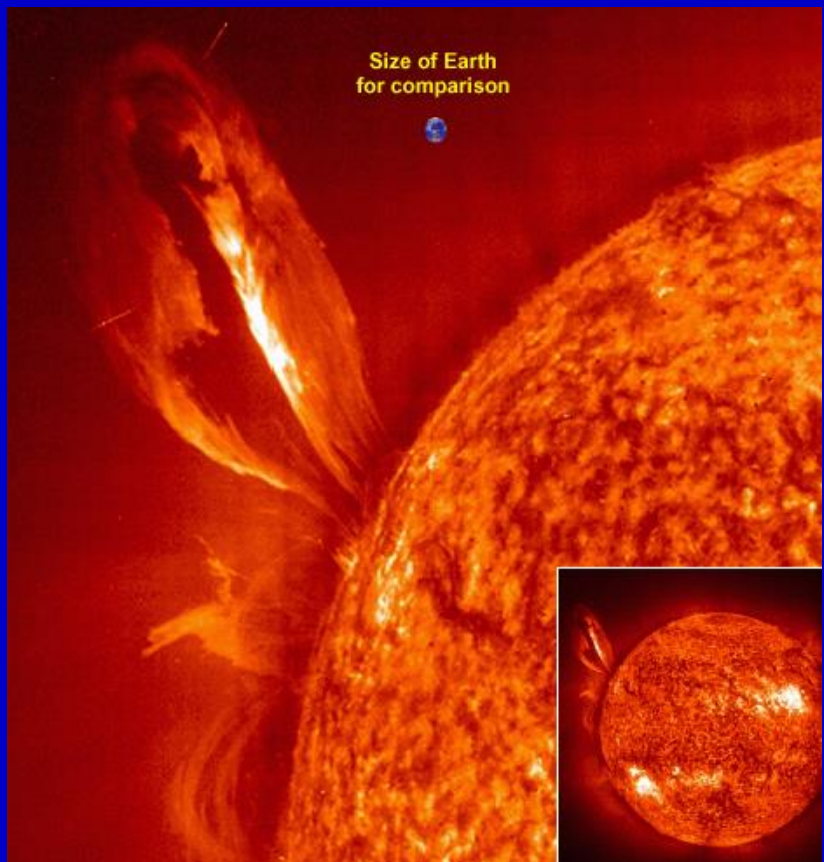
Solar Flares and their Associated CMEs

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



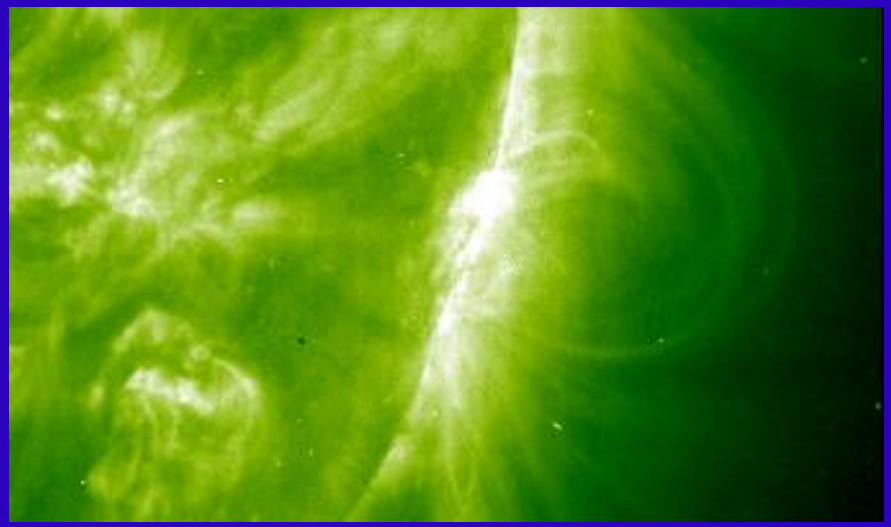


X-Class Major and Extreme Solar Flares Severely Impact HF Ionospheric Propagation

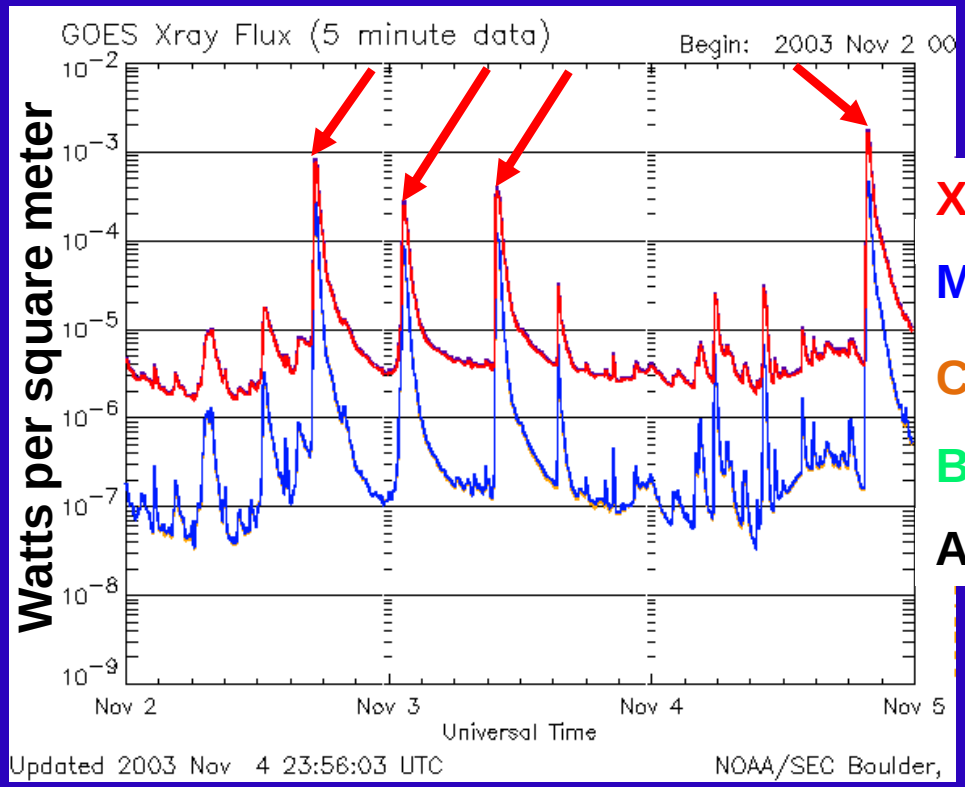
Extreme X10-Class produce long duration hemisphere-wide radio blackouts

Major X-Class produce hemisphere-wide radio blackouts and severe geomagnetic storms especially during the four years near solar maximum

Strong M-Class – medium flares produce less severely degrade HF ionospheric propagation mostly at high latitudes during the seven years near solar maximum



X28 solar flare the largest ever recorded November 4, 2003



Four Major X-Class flares
2 to 4 November 2003

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

Moderate to Severe Daytime HF Radio Blackouts Caused by X-ray Radiation from X-Class Major Solar Flares During the Four Years Near Solar Maximum

X-rays propagating at the speed of light arrive on Earth in 8 minutes
- causing radio blackouts due to extreme D region absorption
- radio blackouts begin suddenly and with no warning

Radio blackouts affect *only* propagation crossing daylight regions

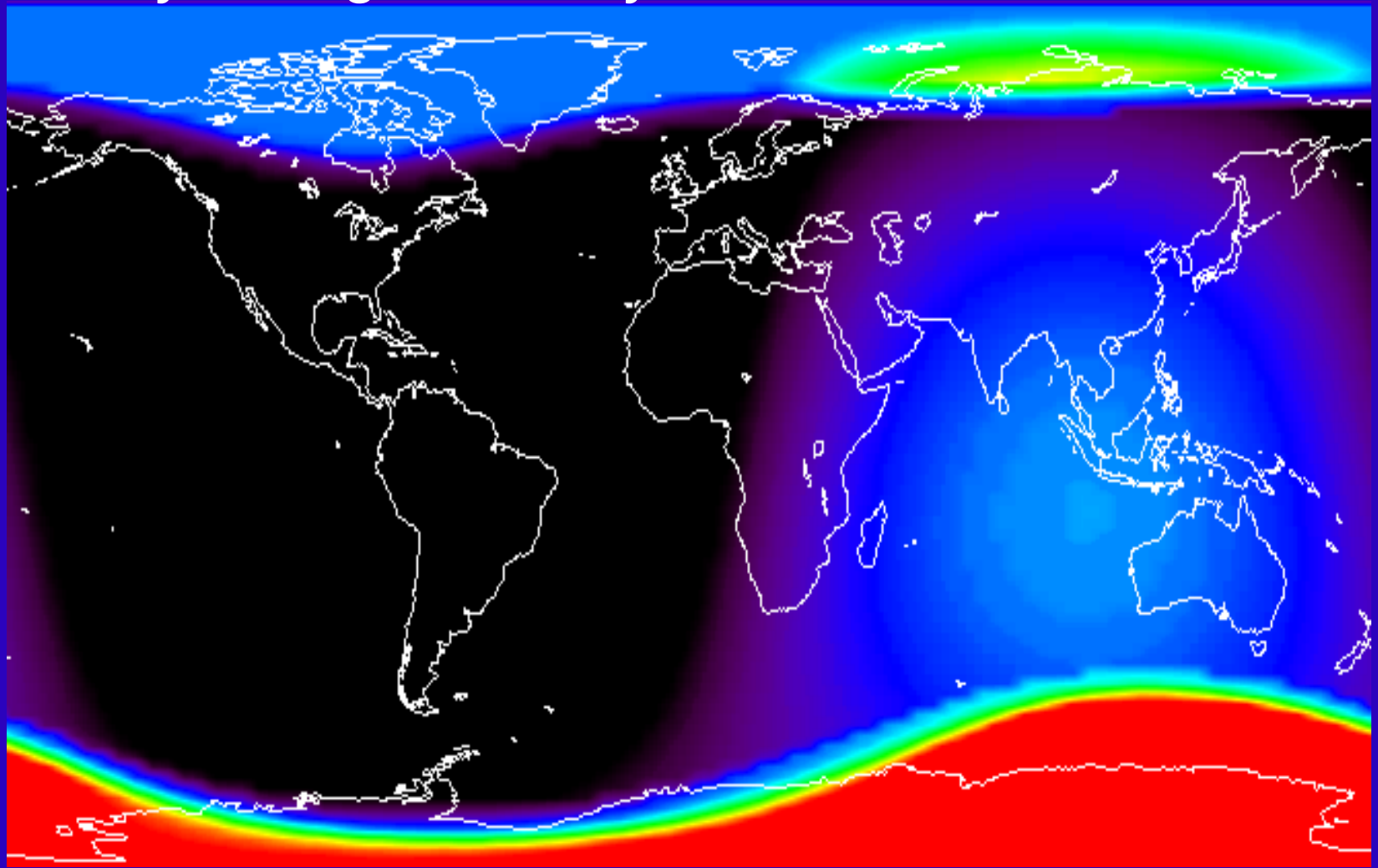
Disrupts HF propagation at lower frequencies for a longer duration and with significantly more D region absorption than higher frequencies

HF ionospheric propagation gradually returns to near pre-blackout conditions about an hour or two after the onset of radio blackouts

Propagation on the higher frequency HF bands returns to near pre-blackout conditions more quickly than the lower frequencies

S2-Class Strong Polar Cap Absorption Events

Typically about 25 S2-Class strong PCAs per solar cycle
S2 PCAs usually last for a few days, sometimes longer
Mostly during the four years near solar maximum



S2-Class Strong Polar Cap Absorption Events

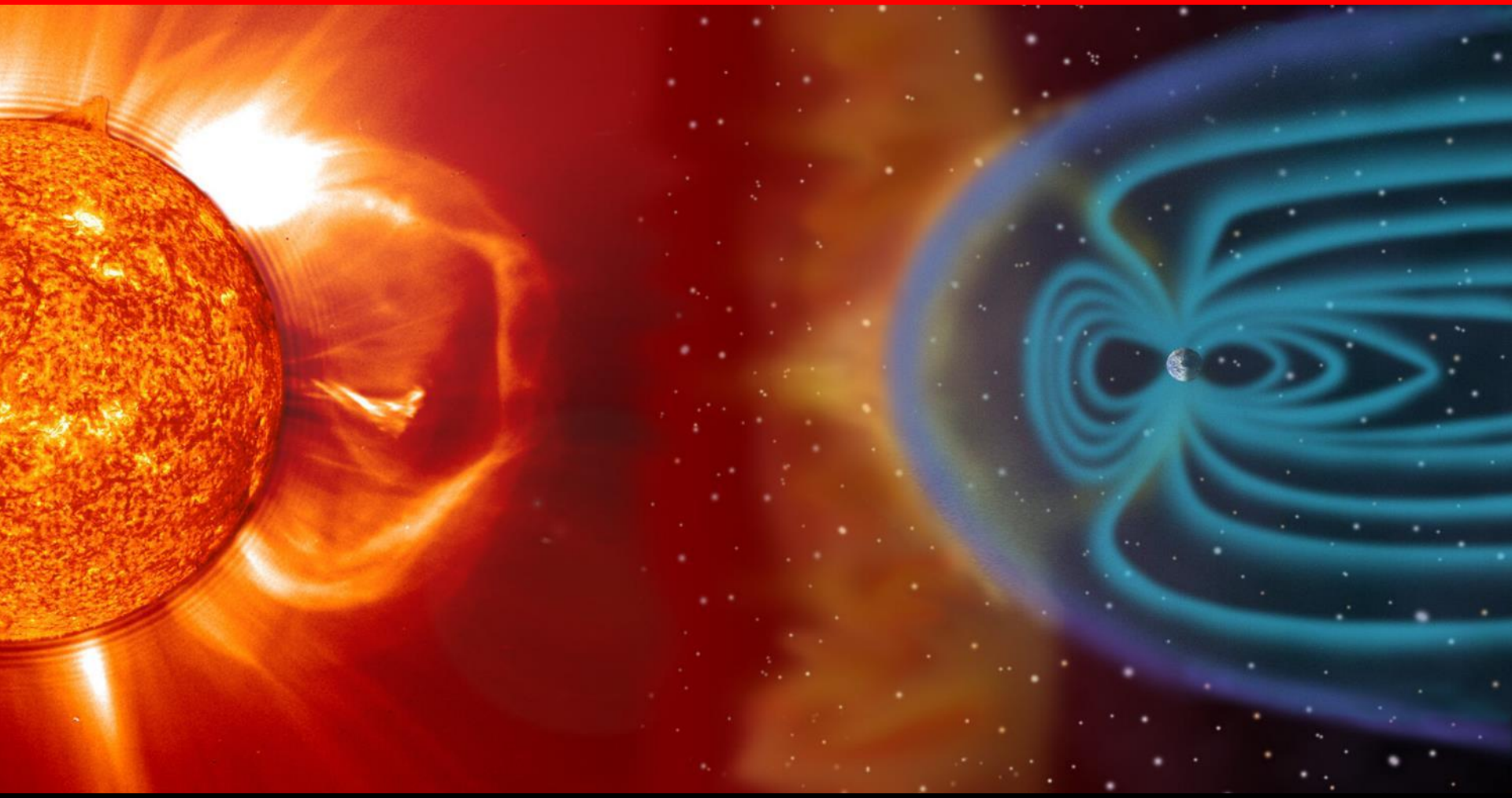
PCA events are caused by Solar Energetic Proton (SEP) radiation from X-Class major solar flares

PCAs significantly absorb (but rarely black out) HF propagation crossing the polar regions

Energetic protons arrive at Earth 10-12 hours after a solar flare
- typically propagate through the interplanetary magnetic field at more than 10 million MPH (1/3 of the speed of light)

Polar cap absorption is much less severe:
- when Earth's winter polar region is tilted away from the sun
- during nighttime hours

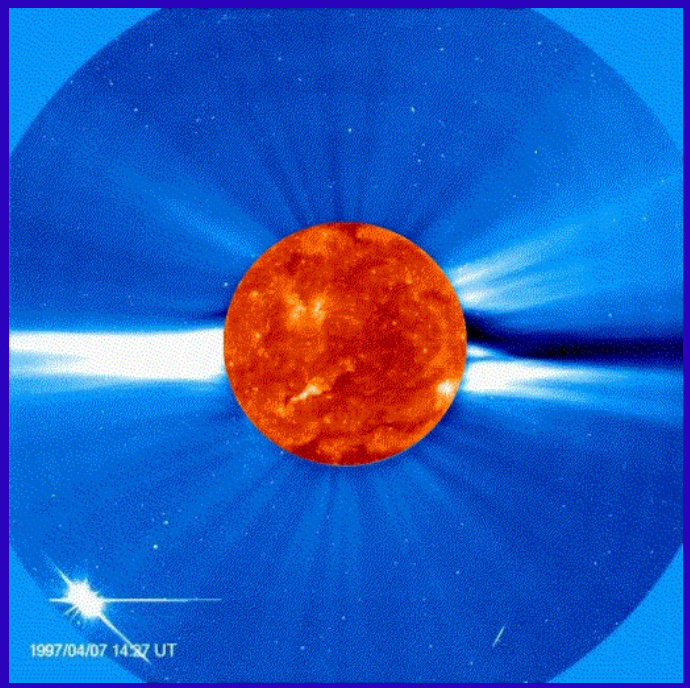
More Frequent Fast Coronal Mass Ejections Through 2026



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

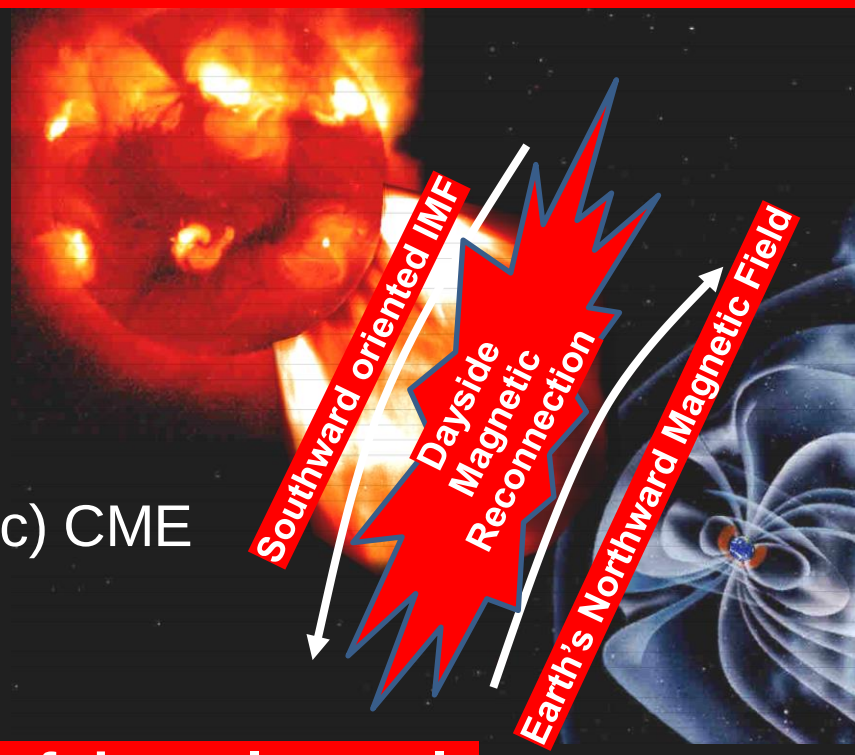


Fast CME impacts are greatly magnified when the Sun's interplanetary magnetic field (IMF) persists in a southward orientation
-- opposite to Earth's magnetic field --
for more than a few hours

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 the IMF persists in a southward
orientation for several hours or more
when enhanced by a fast (>500 km/sec) CME



Fast CMEs occur most 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 or lower, and
- when directed from +/- 30º longitude from the Sun's central meridian

High Level Overview of HF Propagation from Solar Maximum Through 2026

- Solar maximum propagation conditions began in Dec 2022 and continue for about four years through late 2026
- Frequent 10/12 meter DX propagation will continue thru 2026
- 10, 12 and especially 15 and 17 meter worldwide propagation will persist later into the night through 2026 especially during the Spring and Fall equinox seasons
- 20, 30 and 40 meter DX propagation throughout the night will continue frequently through 2026
- Geomagnetic disturbances will gradually become more frequent as low latitude geoeffective large coronal holes become increasingly more frequent through 2026
- Sunspot activity will steadily decline after 2026 until solar minimum propagation conditions begin in about 2029

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 mid-September through late May
  - but not 12 and 10 meters during summer months
- 20 meters provides reliable daytime and nighttime worldwide propagation throughout the year
  - but not during midday hours from June to September
- 30 and 40 meters provides reliable nighttime worldwide propagation throughout the year
- 80 meters often provides good nighttime worldwide propagation from October through April
- 160 meters is a challenging DX band through at least 2026

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

- Worldwide propagation improved dramatically since Oct 2022
  - almost every day from mid-September through late May
  - excellent propagation to Europe from sunrise through early afternoon
  - excellent propagation to Japan and east Asia after 2130Z sometimes continuing for as long as three or four hours is likely to continue through 2016
- Worldwide sporadic-E propagation between northern hemisphere locations will continue -- but very sporadically -- from late May through early August
  - sporadic-E is the dominant June to mid-August propagation

How Solar Maximum Affects 15 and 17 Meter Worldwide Propagation Through 2027

- Worldwide propagation improved dramatically since Oct 2022
  - almost every day from September through late June
  - Excellent propagation to Europe from before sunrise to mid-afternoon
  - excellent propagation to Japan and east Asia after 2130Z sometimes for 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 propagation mode during July through mid-August

How Solar Maximum Affects 20 Meter Worldwide Propagation Through 2027

- Nighttime worldwide propagation improved dramatically since October 2022
  - almost 24 hours 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 15, 12 and 10 meters shortly after our sunrise
- Propagation to Japan and east Asia is strongest for three or four hours after 2130Z, somewhat weaker throughout the night then improves for several hours after local sunrise in the USA
- Midday 20 meter DX propagation is always very poor from June through August because of E region blanketing of F2

How Solar Maximum Affects 40 and 30 Meter Worldwide Propagation Through 2027

- Worldwide propagation throughout the night became much more reliable and more long lasting since October 2022
  - propagation to Europe starts about an hour before sunset
  - continues throughout the night until a few hours after European sunrise when European activity shifts to higher frequency bands
  - the best European propagation and activity is often around European sunrise (0600-0800Z)
- Mid-afternoon propagation to Europe is weaker since 2022
  - most DX activity is still on the higher bands
- Propagation from the east coast to Japan and east Asia is more reliable since 2022 starting at sunset in Japan (0830Z) until about 30 minutes after local USA sunrise

How Solar Maximum Affects 80 Meter Worldwide Propagation Through 2026

- 80 meter DX propagation is usually shorter duration since 2022
  - weak and less reliable DX propagation begins at USA sunset
  - stronger European propagation usually starts several hours after local USA sunset
  - the best European activity is often during the hours before European sunrise
    - continuing until just after European sunrise (0600-0800Z) when most Europeans shift their operations to the higher frequency bands
- 80 meter worldwide propagation will begin to steadily improve after 2026

How Solar Maximum Affects 160 Meter Worldwide Propagation Through 2026

- 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 and sometimes much less
- 160 meter DX propagation will begin to slowly 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

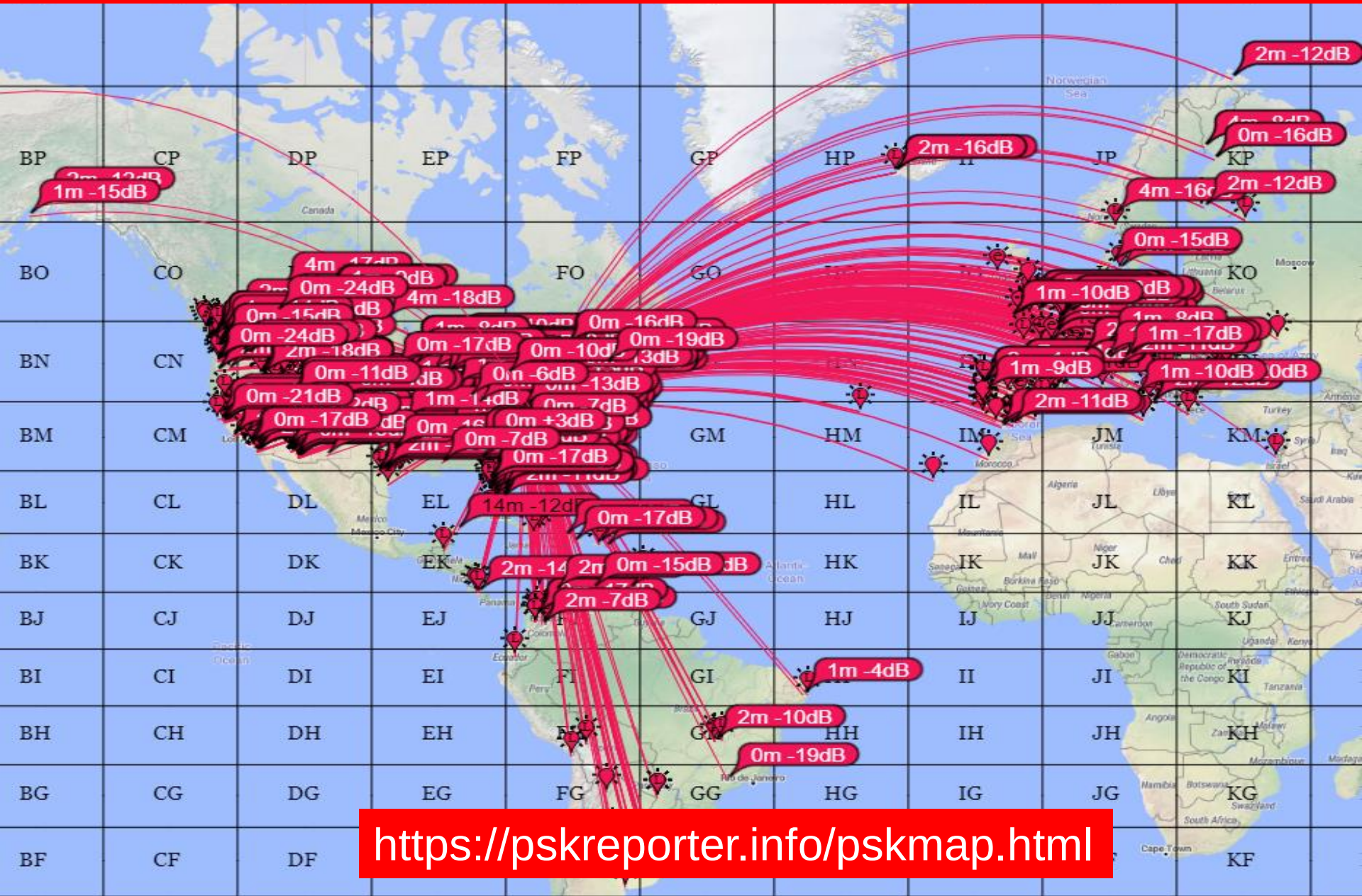
cw rtty psk31 psk63

	● 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 and DX Maps

20 Meters Worldwide FT8 heard in North America 2200Z



https://pskreporter.info/pskmap.html

This Daily Propagation Forecast Was Published by W3LPL in *The Daily DX* 72 hours Before the 2024 ARRL CW DX Contest

The best ARRL CW DX Contest propagation in more than 20 years is likely this weekend

- high sunspot activity
- quiet geomagnetic activity
- quiescent solar wind, and
- low polar cap absorption

www.dailydx.com/trial.html