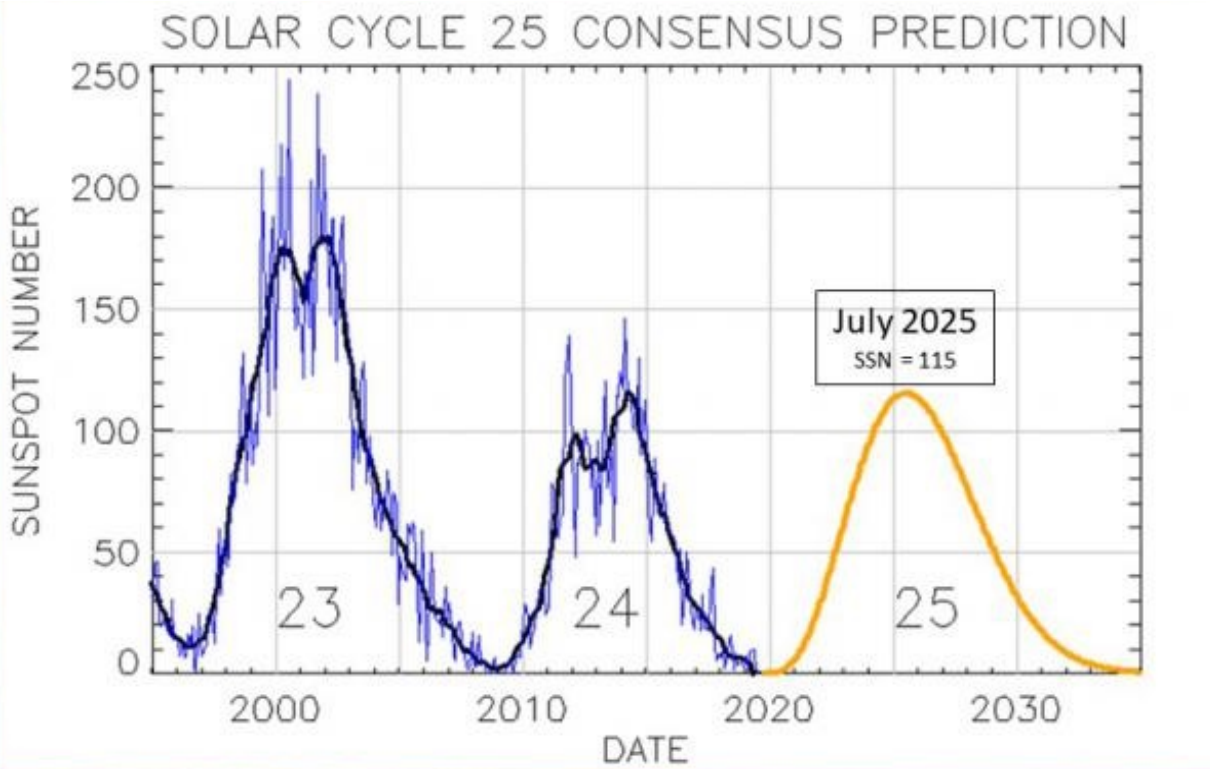
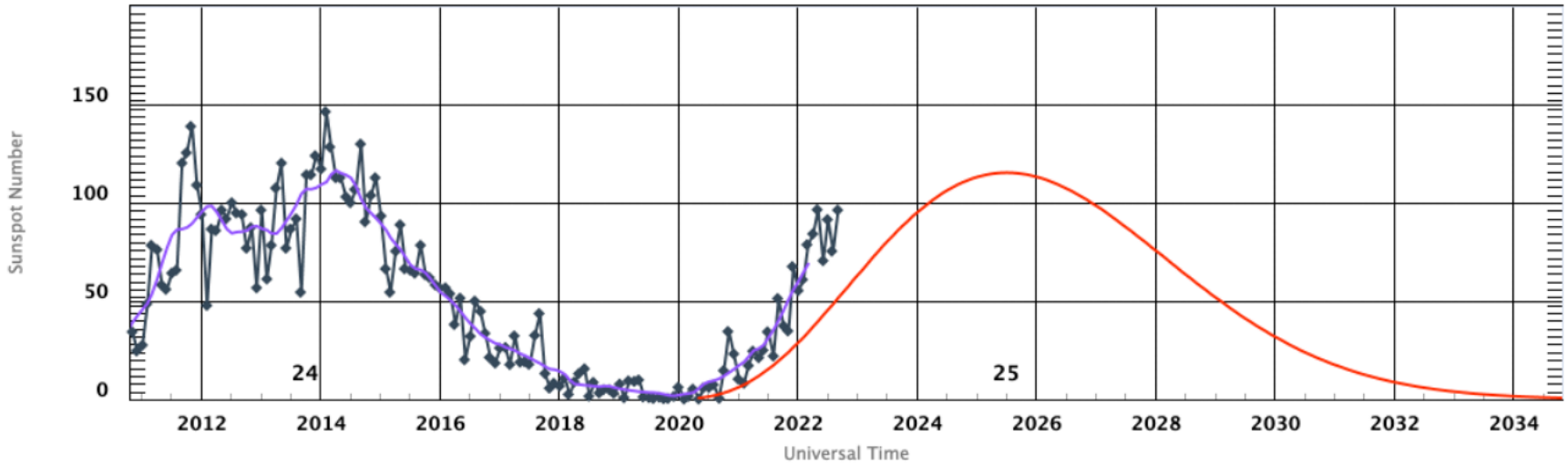
Solar Cycle 25 Update



Ken Larson KJ6RZ
October 2022

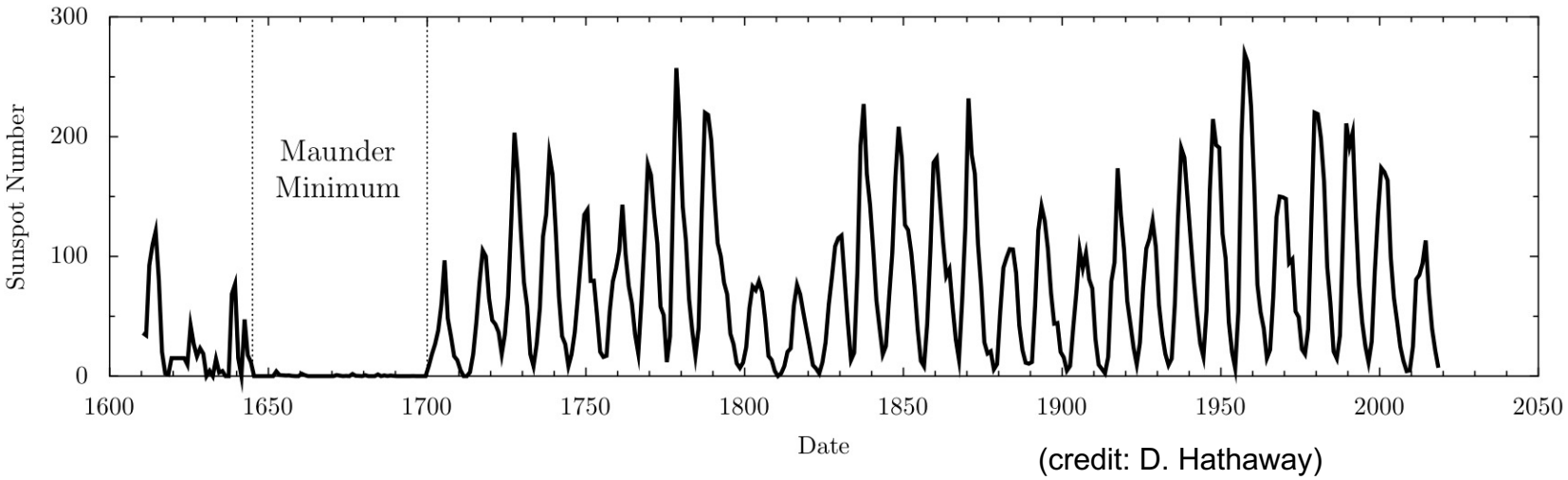
www.skywave-radio.org

Good News



- Solar Cycle 25 is developing faster than anticipated !
- More sunspots appearing than expected

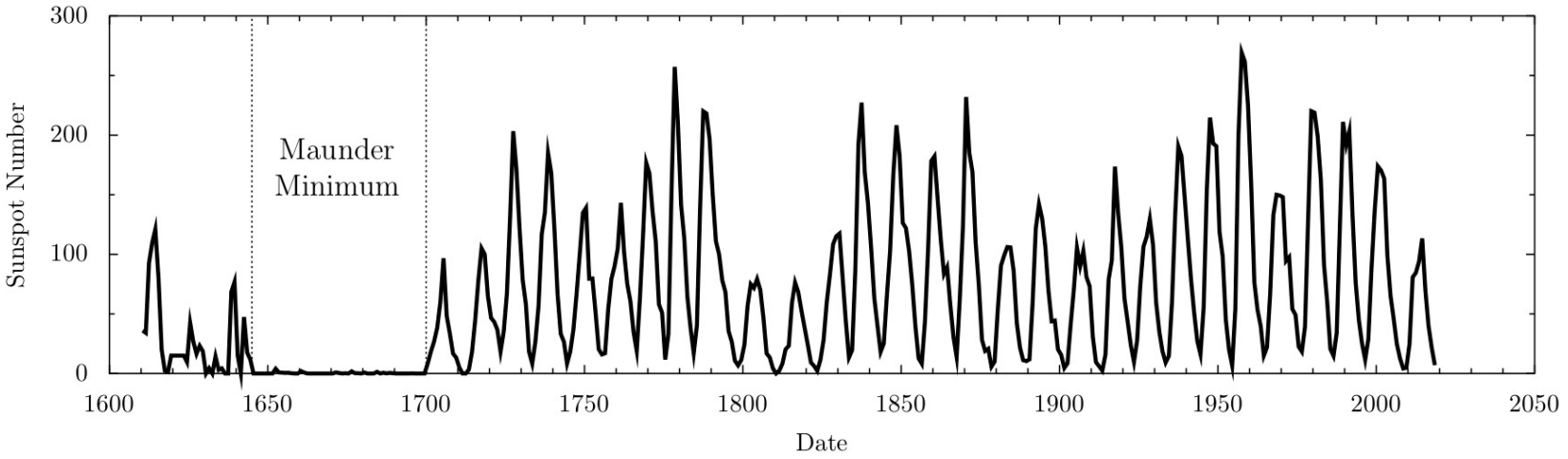
Putting Solar Cycle 25 In Perspective



(credit: D. Hathaway)

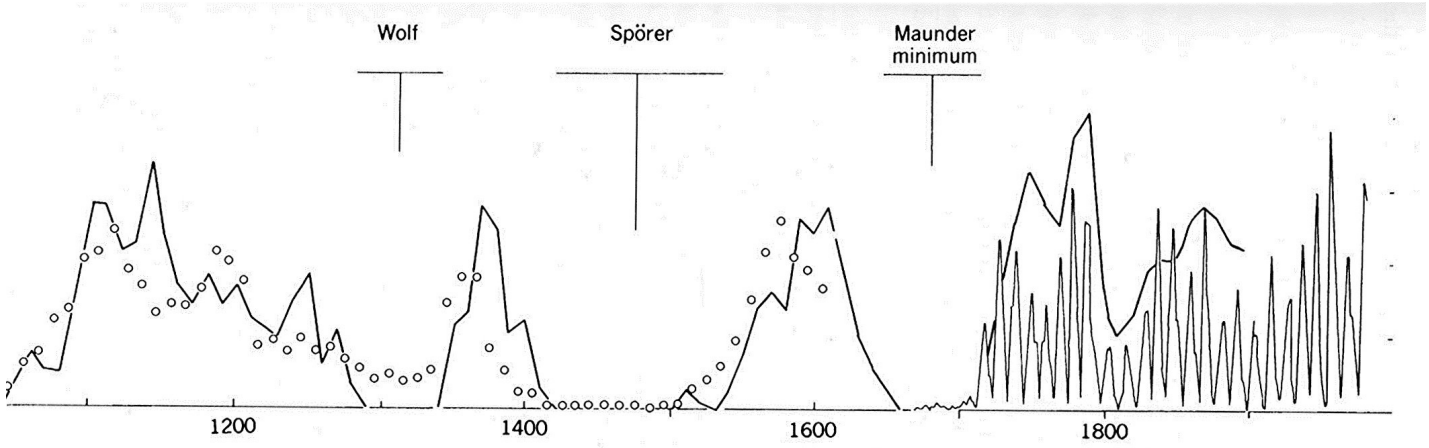
- Sunspots have been studied for over 400 years.
  - 1610 Galileo began observing the Sun with his telescope
- What is interesting in this picture is
  - The Maunder Minimum
  - Periodic dips in the amplitude of solar cycles
- Periodic amplitude dips occur every 80 to 120 years

Maunder Minimum



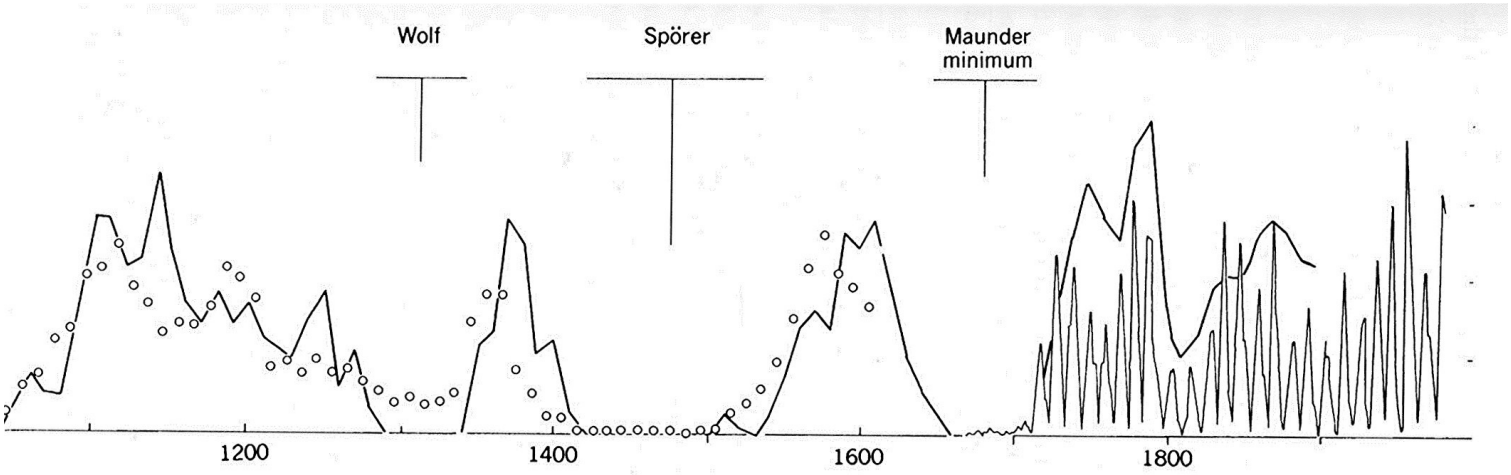
- For 70 years, from 1645 to 1715, there were few if any sunspots visible on the Sun.
- That was a long time ago.
- One could speculate that astronomers and scientists at the time were not vigilant in observing the Sun.
- However, records show that the Sun was continuously and carefully observed.
- There simply were not any sunspots.

Other Prolonged Solar Minimums



- There have been other prolonged solar minimums throughout history
- Evidence of earlier prolonged minimums provided by carbon-14 in tree rings
  - Carbon-14 produced by energetic cosmic rays colliding with nitrogen in Earth's upper atmosphere
  - Carbon-14 makes its way down to the lower atmosphere, is absorbed by tree leaves through photosynthesis, and ends up in tree rings as trees grow.
  - During solar maximum the Sun's intensified magnetic field partially shields the Earth from cosmic rays resulting in less carbon-14 being produced.

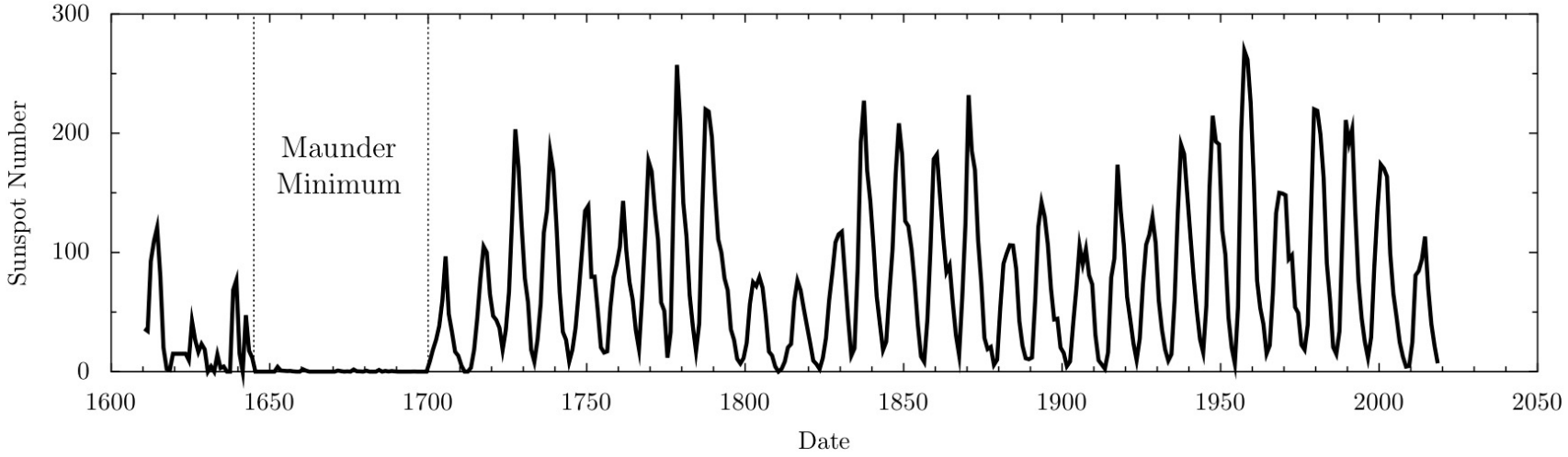
Implication



(Credit: J. Eddy)

- The fairly regular behavior of the sunspot cycles over the last 300 years may NOT be the norm.
- It appears that prolonged solar minimums occur at regular intervals
- Are we over due for the next prolonged minimum !
- Hopefully not

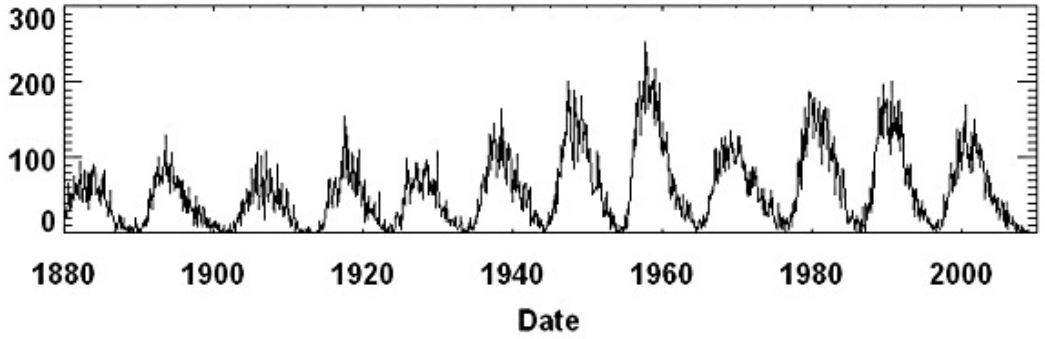
Periodic Amplitude Dips



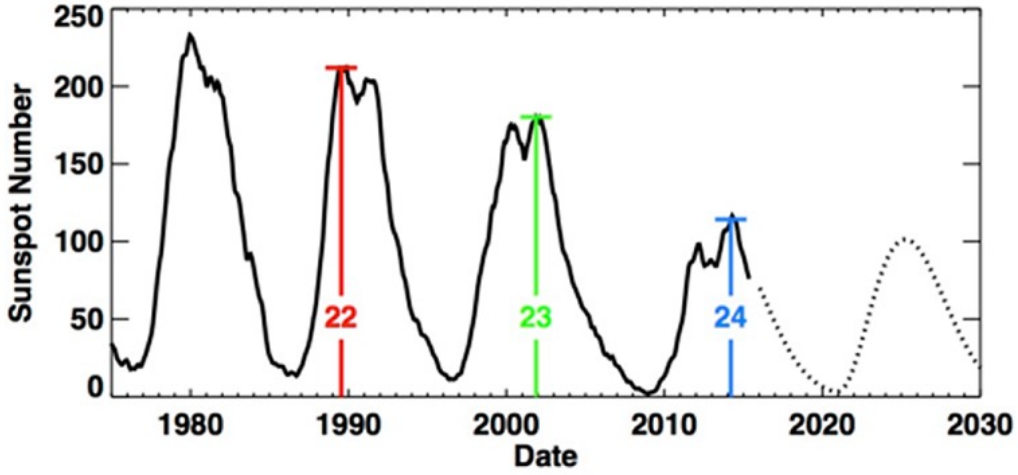
(credit: D. Hathaway)

- Periodic amplitude dips occur every 80 to 120 years
- One occurred around 1815
- Another one occurred in 1908
- Is one occurring now?

Sunspot Activity Weakening



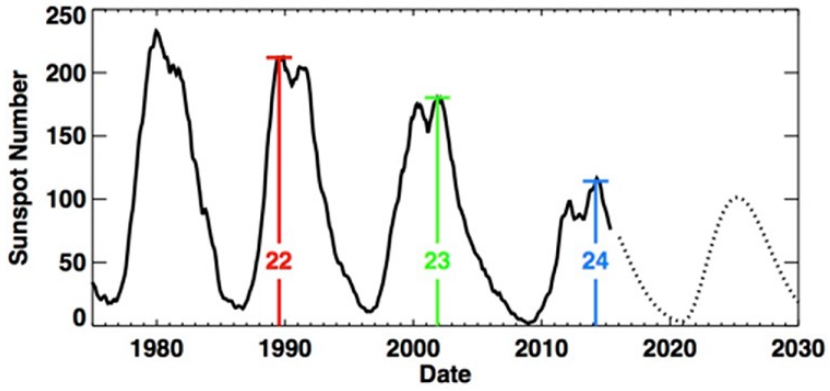
(credit: SpaceWeather.com)

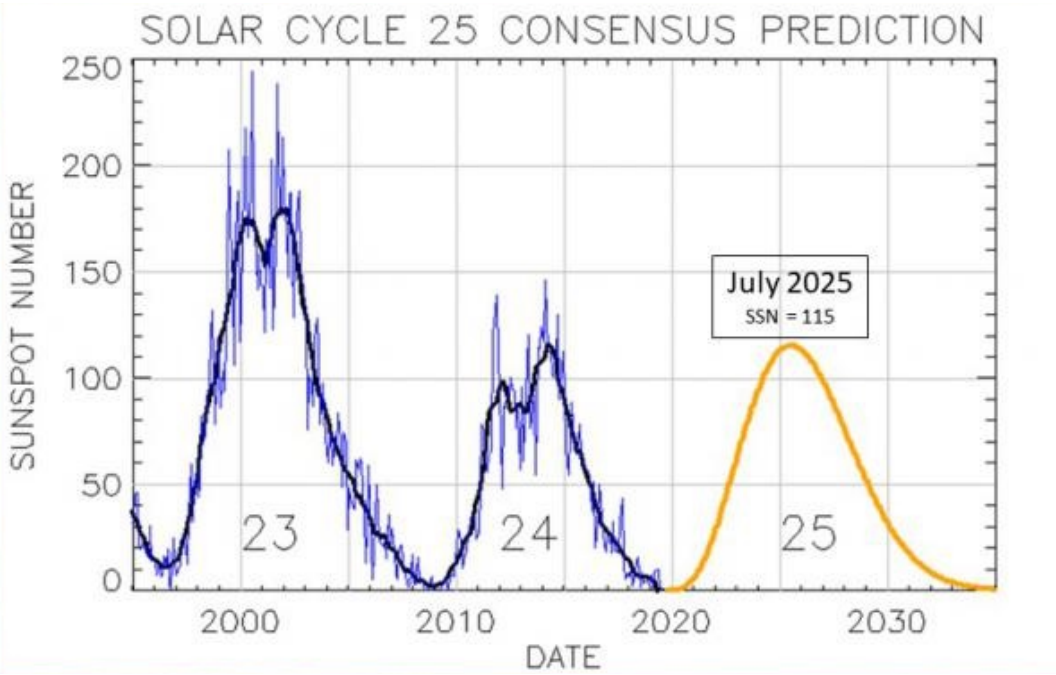


(credit: D. Hathaway)

- Sunspot cycles were relatively consistent from 1880 – 1928.
- Sunspot activity increased from 1928, peaking in 1957.
- Since 1980 sunspot activity has slowly declined.

Is Solar Cycle 25 The 100 Year Dip?

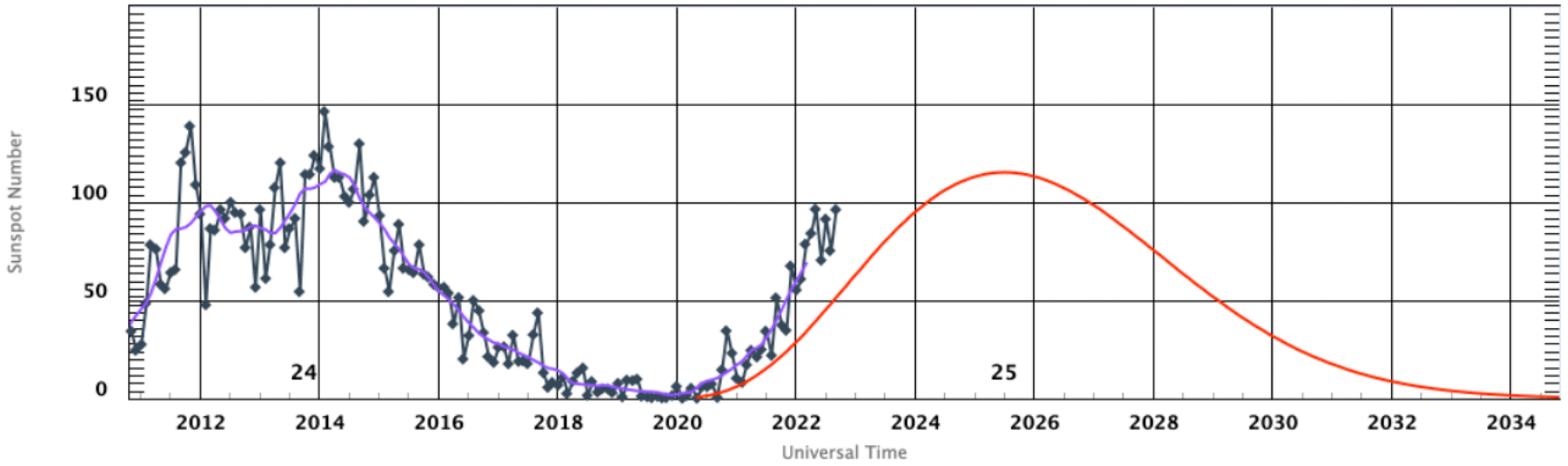




(credit: NOAA Space Weather Prediction Center)

- The hope has been that Solar Cycle 25 would be the 100 year amplitude dip
- With conditions beginning to improve during Solar Cycle 26
- But maybe not

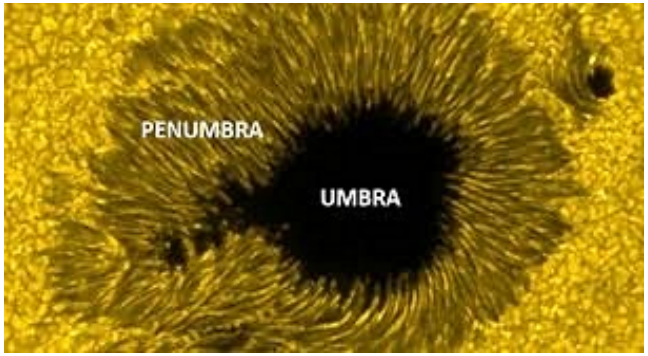
Solar Cycle 24 May Have Been The 100 Year Dip



- It now appears that Solar Cycle 24 may have been the 100 year amplitude dip
- We could already be in recovery with Solar Cycle 25 exhibiting
  - More solar activity
  - Greater number of sunspots, etc.

What Exactly Are Sunspots

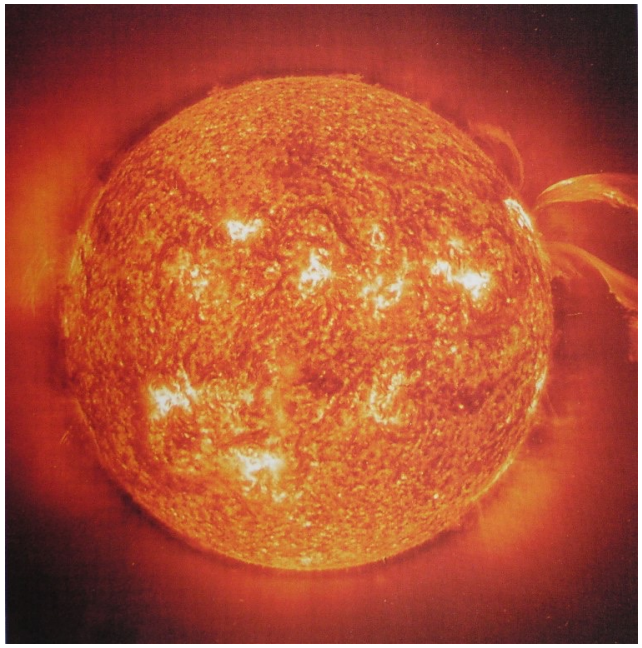
(credit: NASA Goddard Space Flight Center)



(credit: spaceweatherlive.com)

- Sunspots formed by magnetic fields erupting through Sun's surface (the photosphere)
- Sunspots are black in color because they are cooler than surrounding photosphere
- The Earth could be easily "dropped" into the umbra and disappear forever.
- Sunspots appear, last several days, some several weeks, and then disappear.
- Sunspots themselves do not do much for us
- Their temperatures are too low to produce EUV radiation need to ionize Earth's atmosphere.
- However, sunspots are markers for solar activity that does affect us

Plages

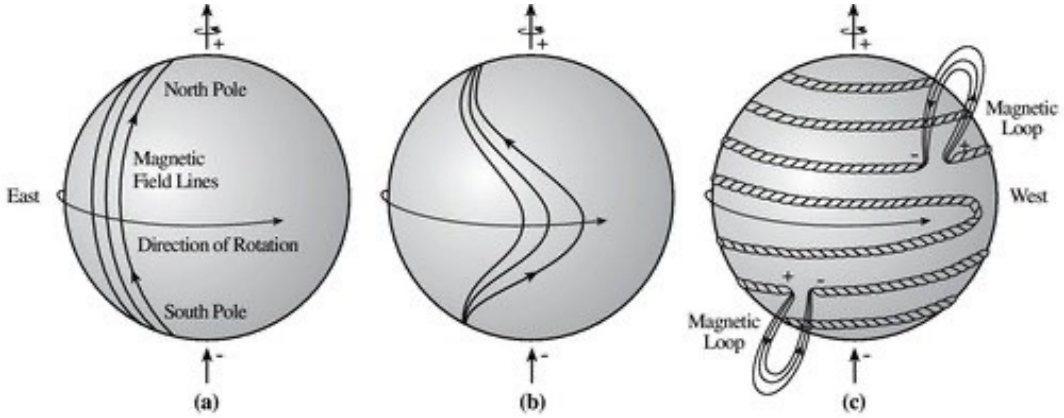


Sun at H alpha wavelength

(credit: NOAA)

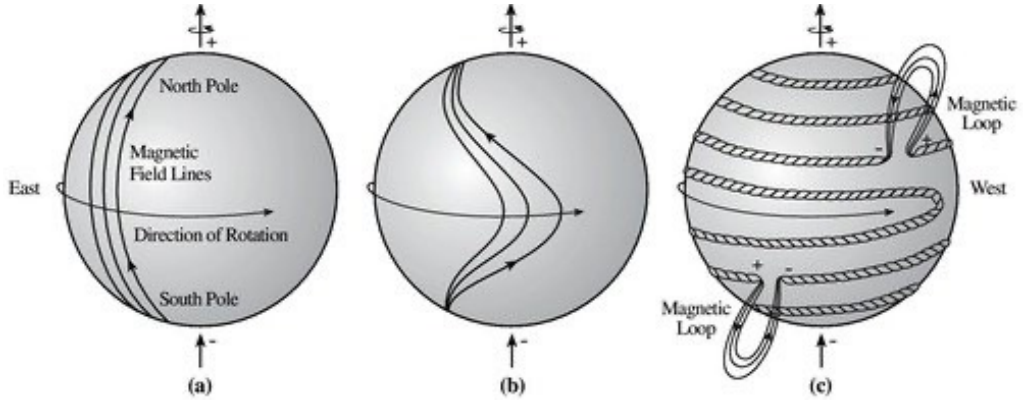
- Plages are hot irregularly shaped regions in the chromosphere
- Plages usually, but not always, are found near sunspots.
- Plages form before sunspots appear, and disappear some time after sunspots in the region have vanished.
- **Plages are difficult to see**
- However, sunspots are easy to see and thus act as markers indicating the locations and number of plages present.
- **Plages emit copious amounts of extreme ultra violate radiation (EUV) needed to ionize Earth's upper atmosphere**

Why Solar Cycles Occur



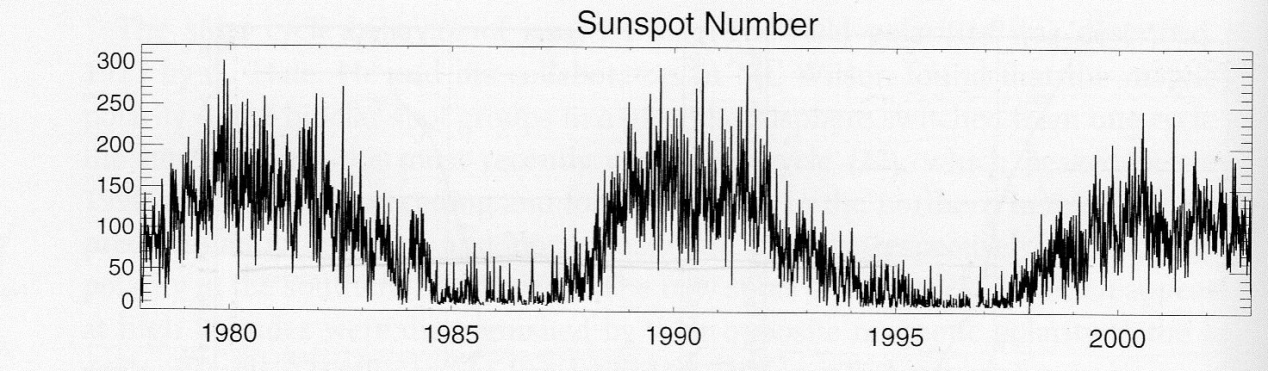
- Solar cycles are caused by the Sun's differential rotation – Sun's equator rotates faster than its poles
- Uniform north-south magnetic field at solar minimum, strength = 1 gauss
- Differential rotation stretches out magnetic field lines along equator
- Magnetic field becomes wrapped around the Sun many times
- Winding the magnetic field around the Sun in tighter ever increasing number of turns is not a sustainable process. Something has to break, and it does!

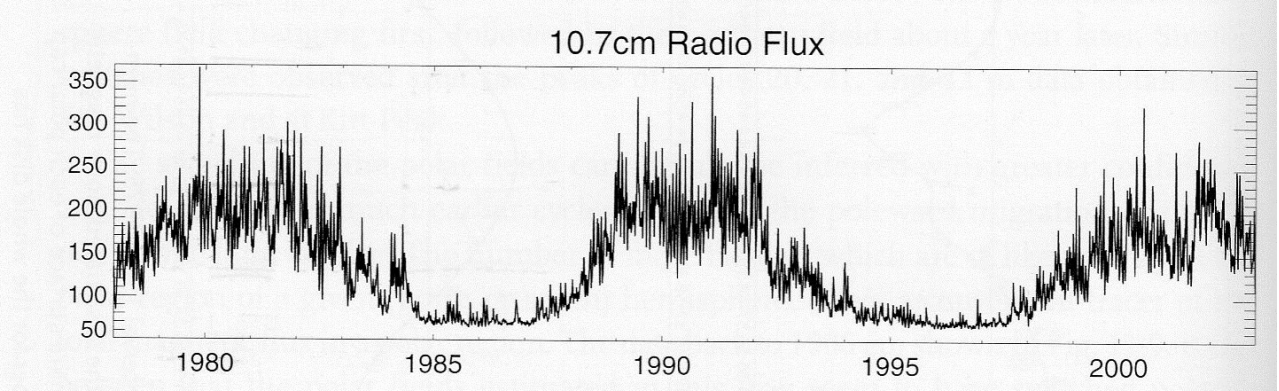
Why Solar Cycle Occurs - continued



- Continued winding, twisting, and knotting creates tremendous stress in the magnetic field driving field intensities to well over 3,000 gauss.
- The enormous stress eventually causes the field to rupture in many places.
- As it does so high arching prominences, coronal loops, sunspots, and solar flares erupt from the Sun.
- The Sun reaches solar maximum during this very turbulent phase of the solar cycle with large numbers of sunspots visible on the solar surface.
- As the magnetic field disintegrates, sunspots gradually disappear and the Sun again approaches solar minimum with a quiet north-south magnetic field.

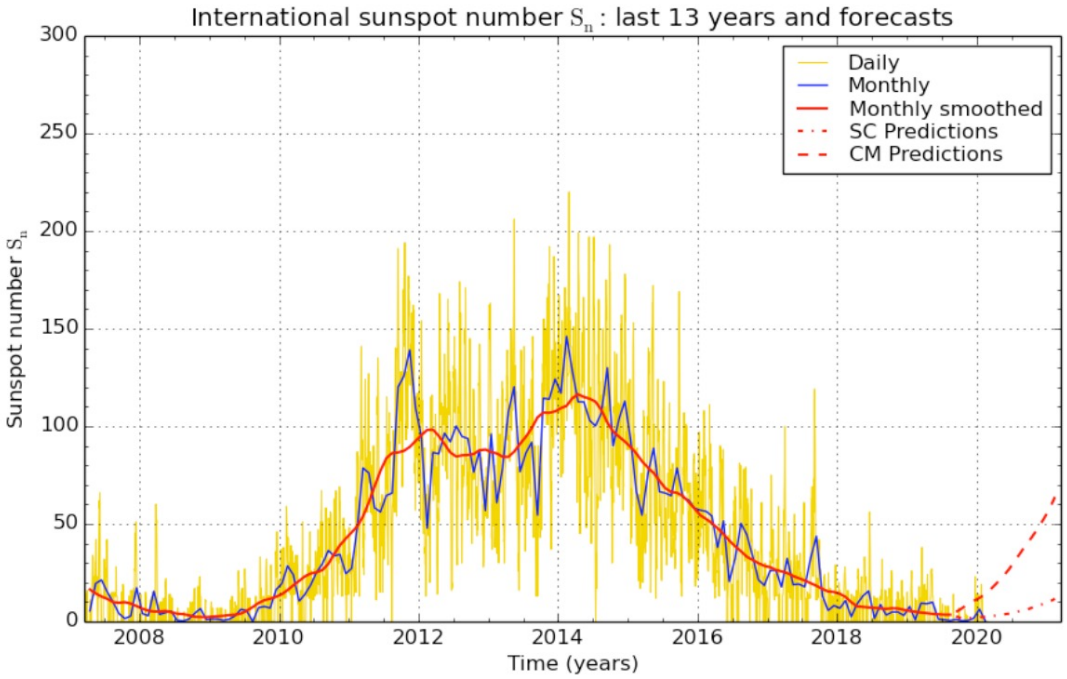
Sunspot Number vs Radio Flux





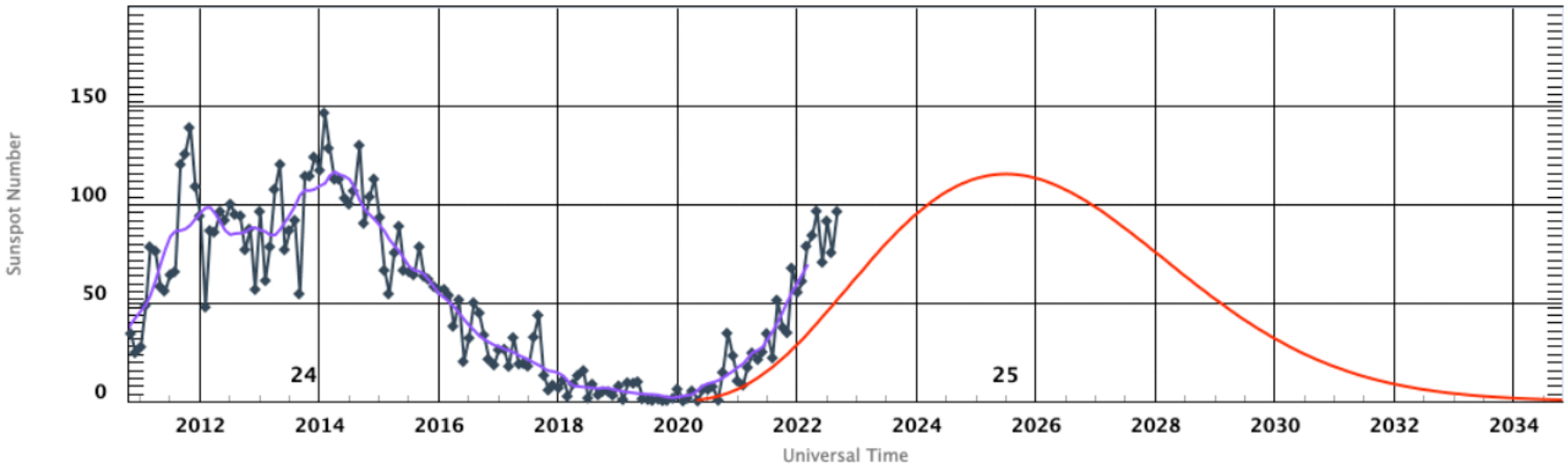
- Sunspot number is a visual indication of solar activity
- The 10.7 cm (2.8 GHz) radio frequency solar flux index (SFI) is an electromagnetic indicator of solar activity. Solar Min $65 < SFI < 225$ Solar Max
- Both measures track very closely

Smoothed Sunspot Number (SSN)



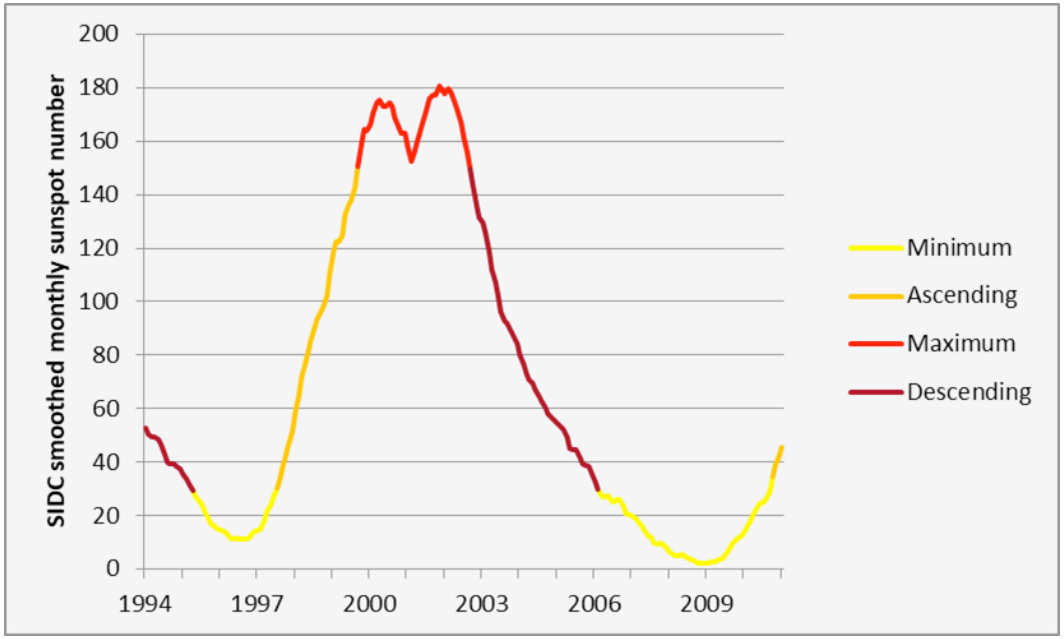
- Sunspot number SN is the current number of sunspots visible.
- The monthly Smoothed Sunspot Number SSN is the average of the monthly mean sunspot numbers over 13 months from 6 months before to 6 months after the month of interest. SSN is one of the most widely used indices for ionospheric work.
- For SSN calculations, months have the same weighting except for the first and last months in the series each of which is given a weighting of one half (0.5).

Solar Cycle 25 Sunspot Number Progression



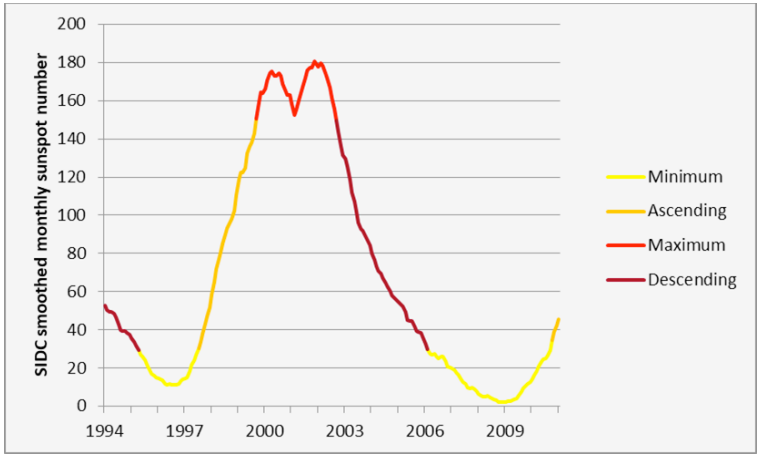
- Black diamonds = Monthly average sunspot values
- Purple line = Monthly Smoothed Sunspot Numbers (SSN)
- Red line = Predicted values

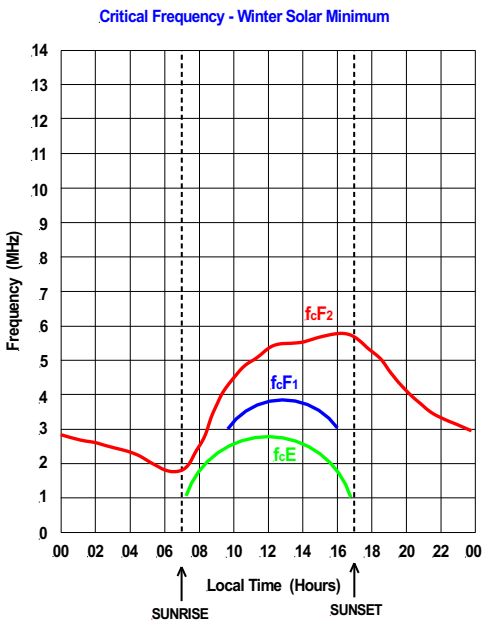
What To Expect Going Forward

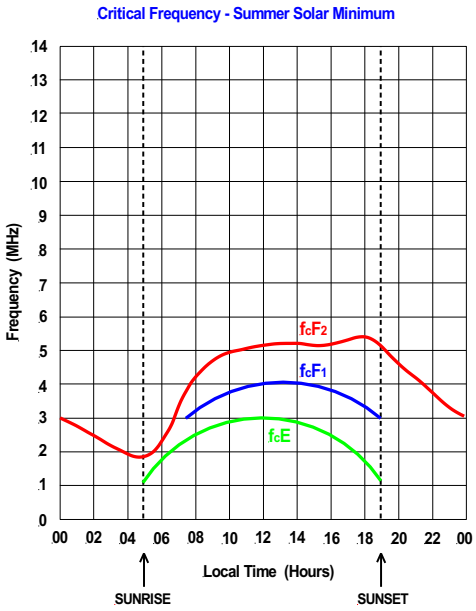


- A solar cycle, illustrated here by Solar Cycle 23, has 4 phases
  - Solar Minimum (yellow)
  - Ascending phase (orange)
  - Solar Maximum (red)
  - Descending phase (brown)

We Have Left Solar Minimum

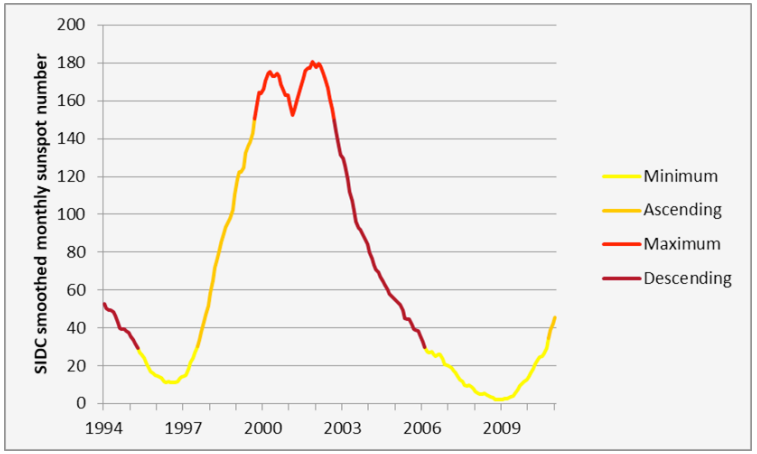




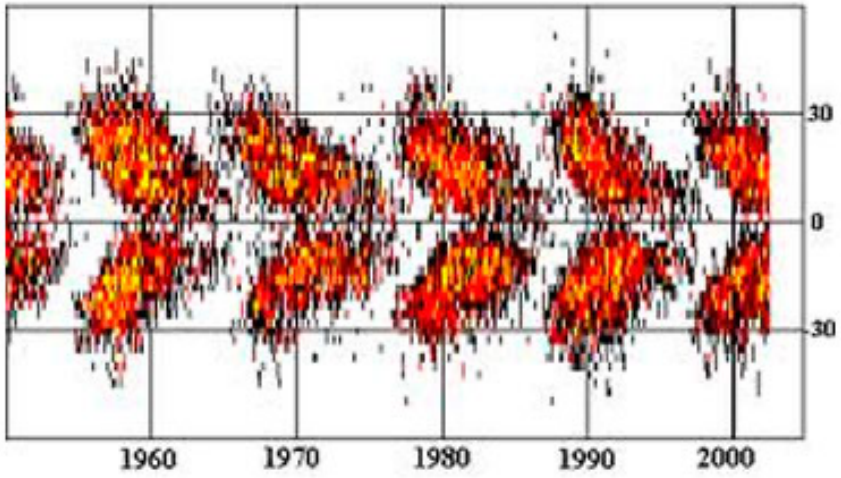


- Solar minimum is the period of few if any sunspots visible on the Sun.
- The lowest levels of Extreme Ultra-Violate (EUV) radiation from the Sun
- Ionosphere poorly ionized
- Low ionospheric critical frequencies values
- Generally poor HF conditions
- Solar minimum roughly occurred from 2018 through 2021

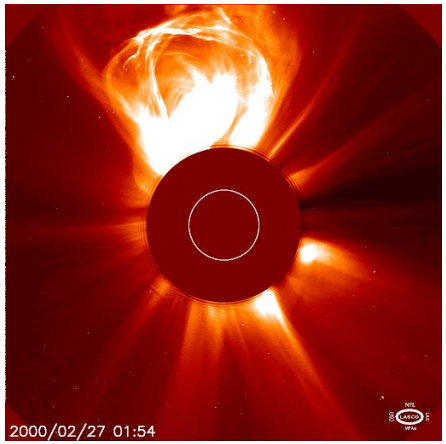
We Are Now In The Ascending Phase



- Solar activity slowly beginning to increase.
- Sunspots begin to appear at high solar latitudes
- Small increase in Coronal Mass Ejections (CME)
- Small increase in geomagnetic and ionospheric storms

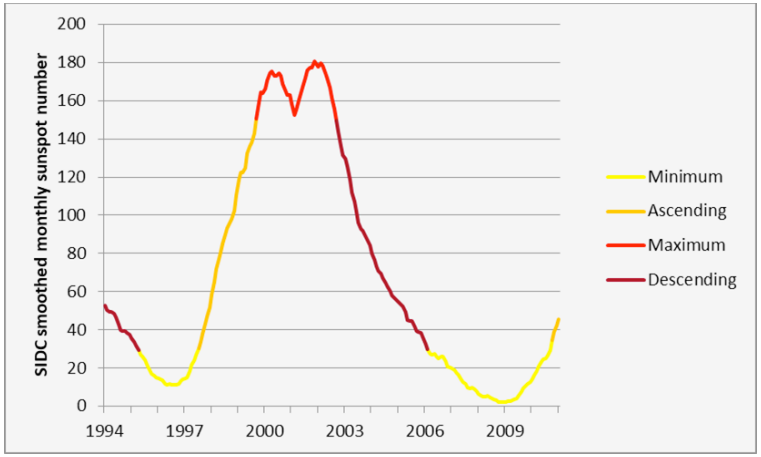


Sunspot cycle

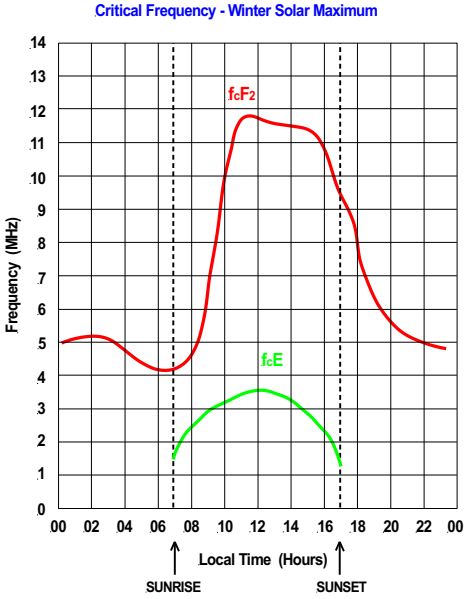


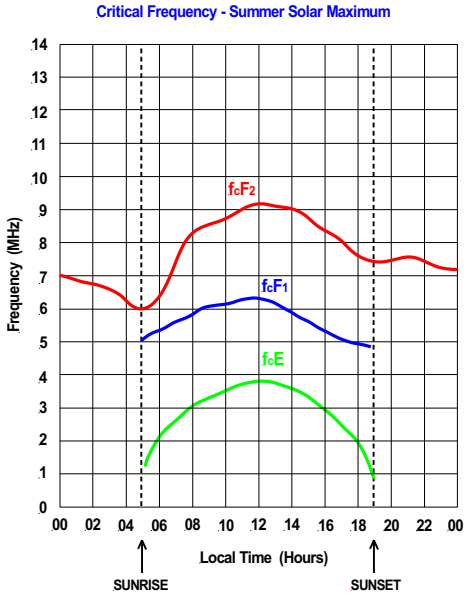
CME

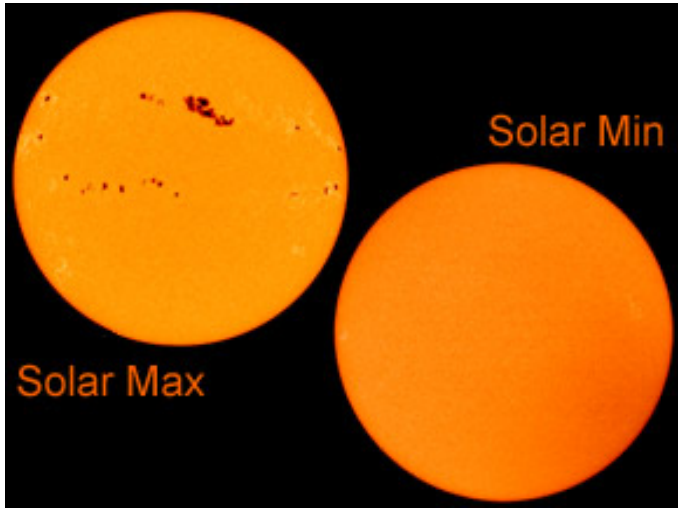
Solar Maximum



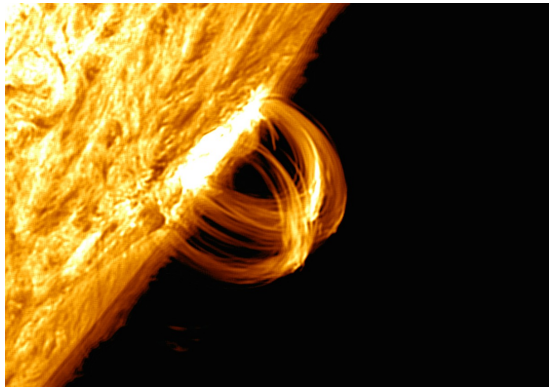
- Most active period of the solar cycle
- Large numbers of sunspots
- High levels of EUV and x-ray radiation
- Ionosphere highly ionized
- High critical frequencies







During Solar Maximum



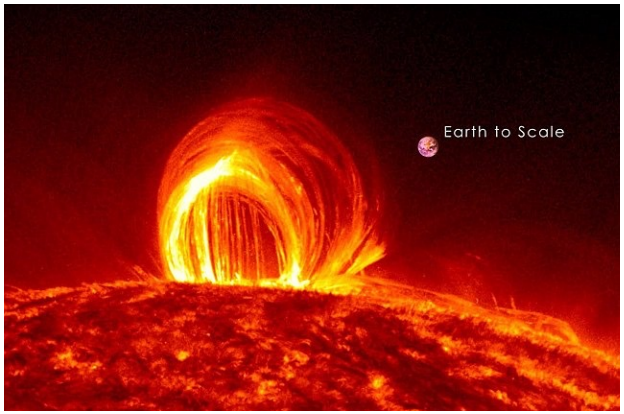
- Solar prominences
- Large coronal loops
- Frequent solar flares
- Coronal mass ejects occur often
- Significant increase in ionospheric storms

Solar Flares

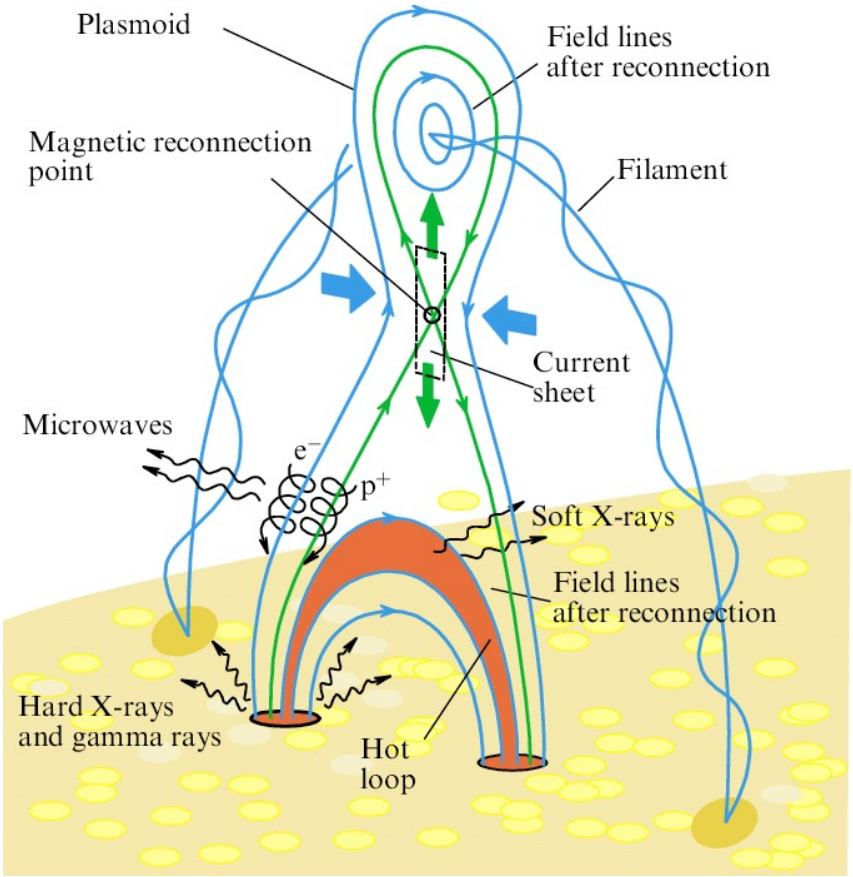
- As over the horizon radio operators
- We need to know something about solar flares
- So that we can deal with them

A Solar Flare

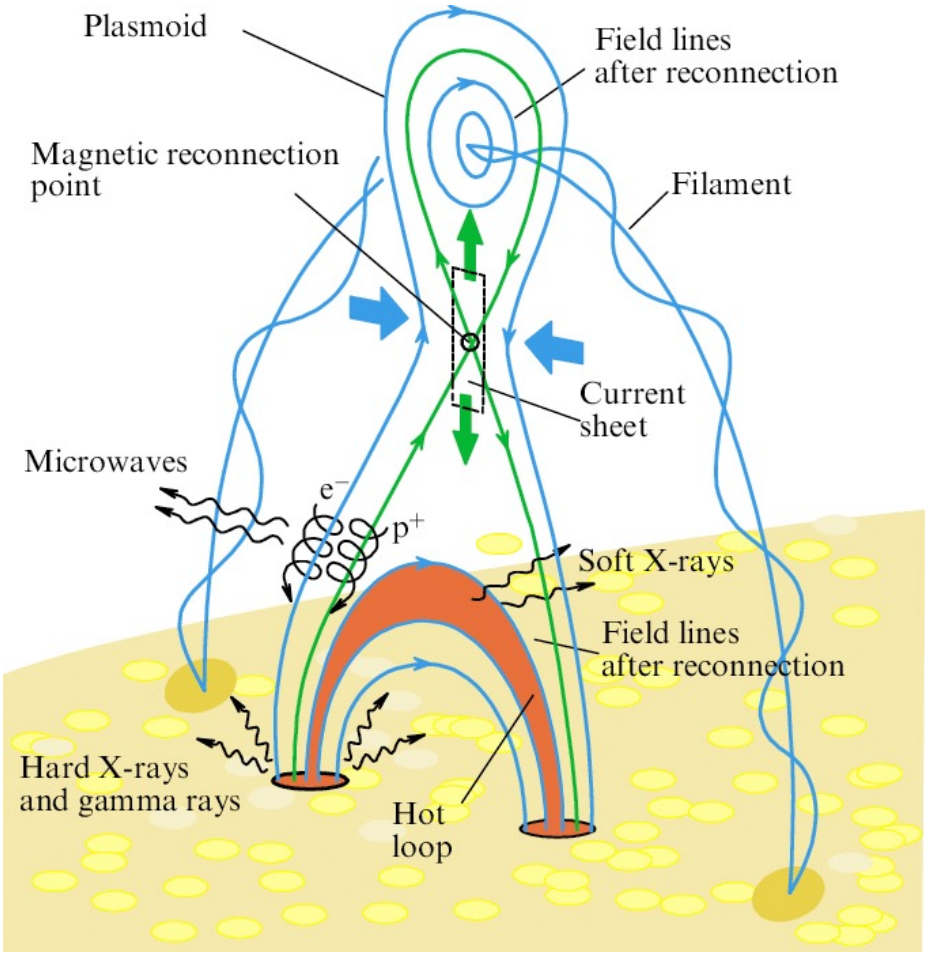
Coronal Loop



- A solar flare is a massive, sudden, explosive release of energy stored in a coronal loop
- The problem is that the anchor points of a coronal loop move, but not together
- As they move the coronal loop becomes stretched out, twisted, and tangled into an hour glass shape



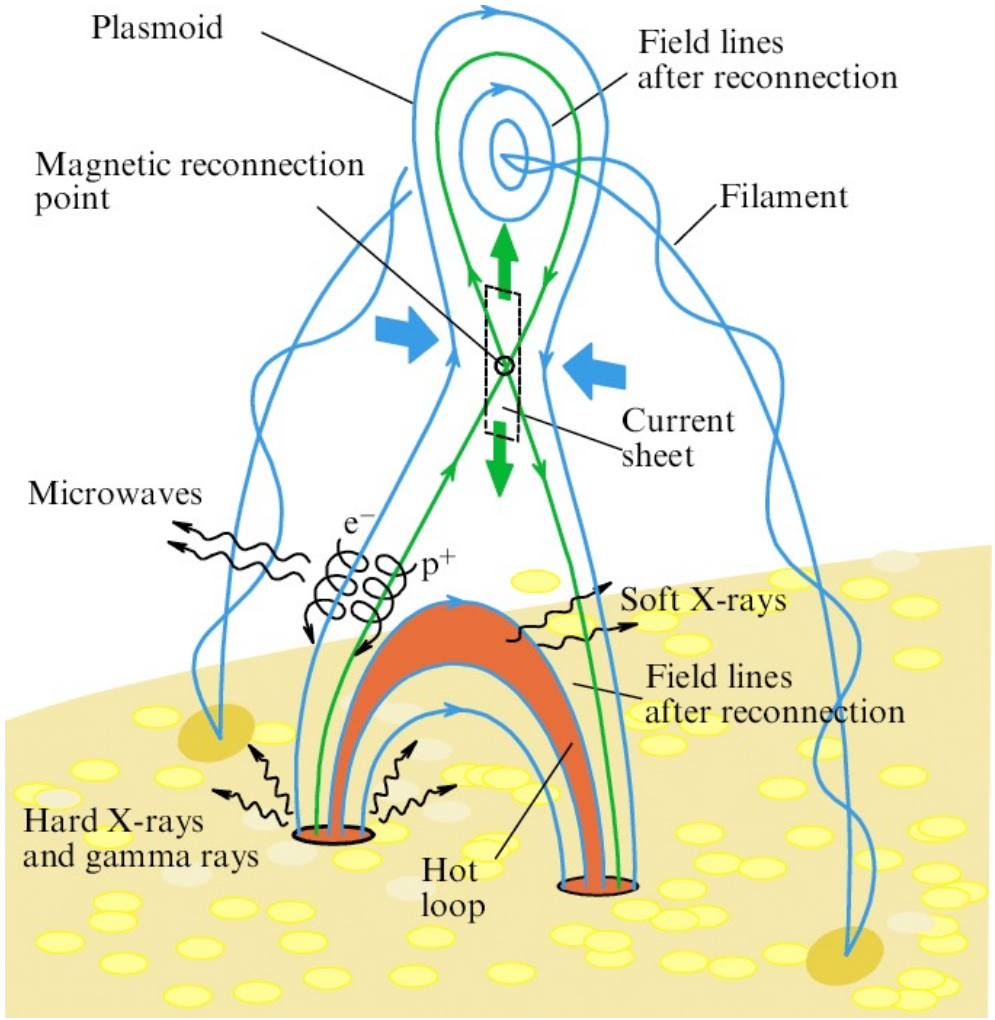
Magnetic Short Circuit Initiates A Solar Flare



- Outbound and returning magnetic field lines (green) are squeezed closer and closer together (forming the hour glass neck)
- Energy buildup becomes so great that outbound and returning magnetic field lines "short circuit" **initiating a solar flare.**

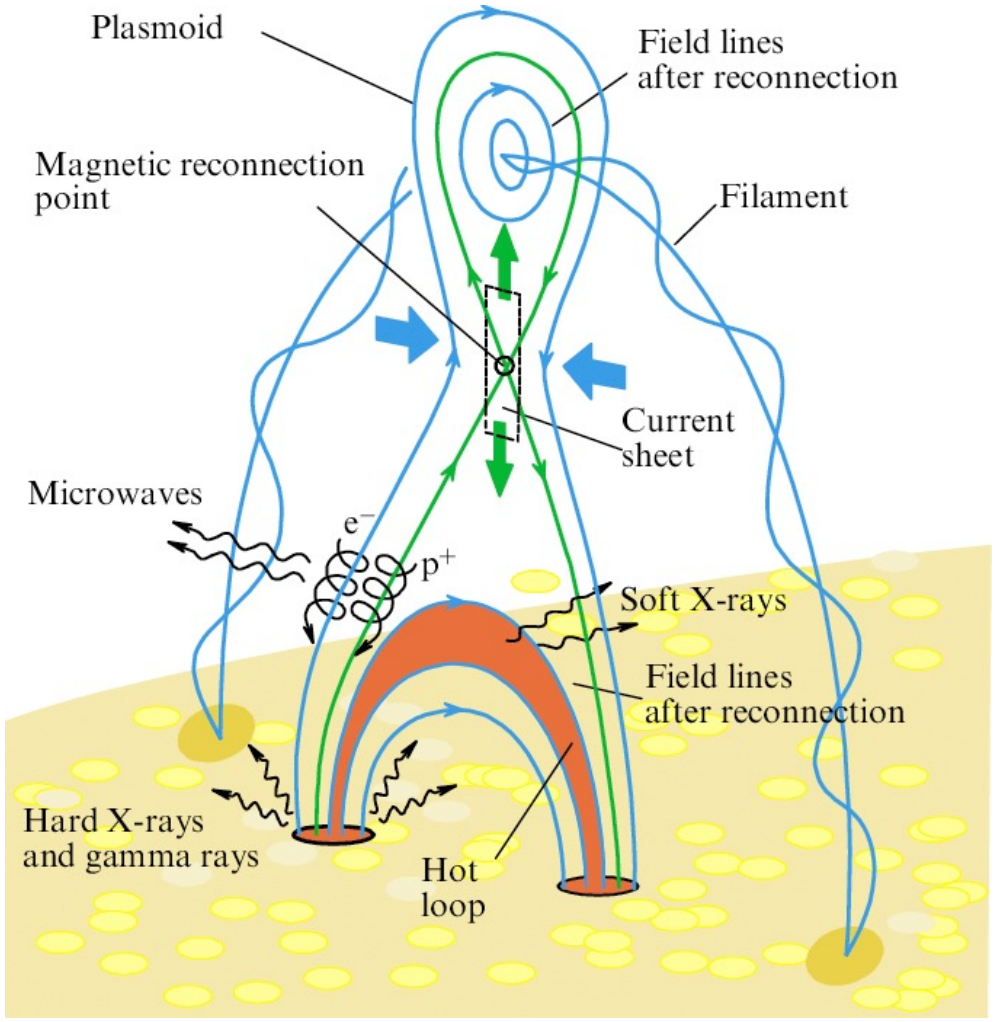
Energy released is equivalent to millions of 100 – megaton hydrogen bombs exploding all at once.

Solar Flare – Below The Rupture Point



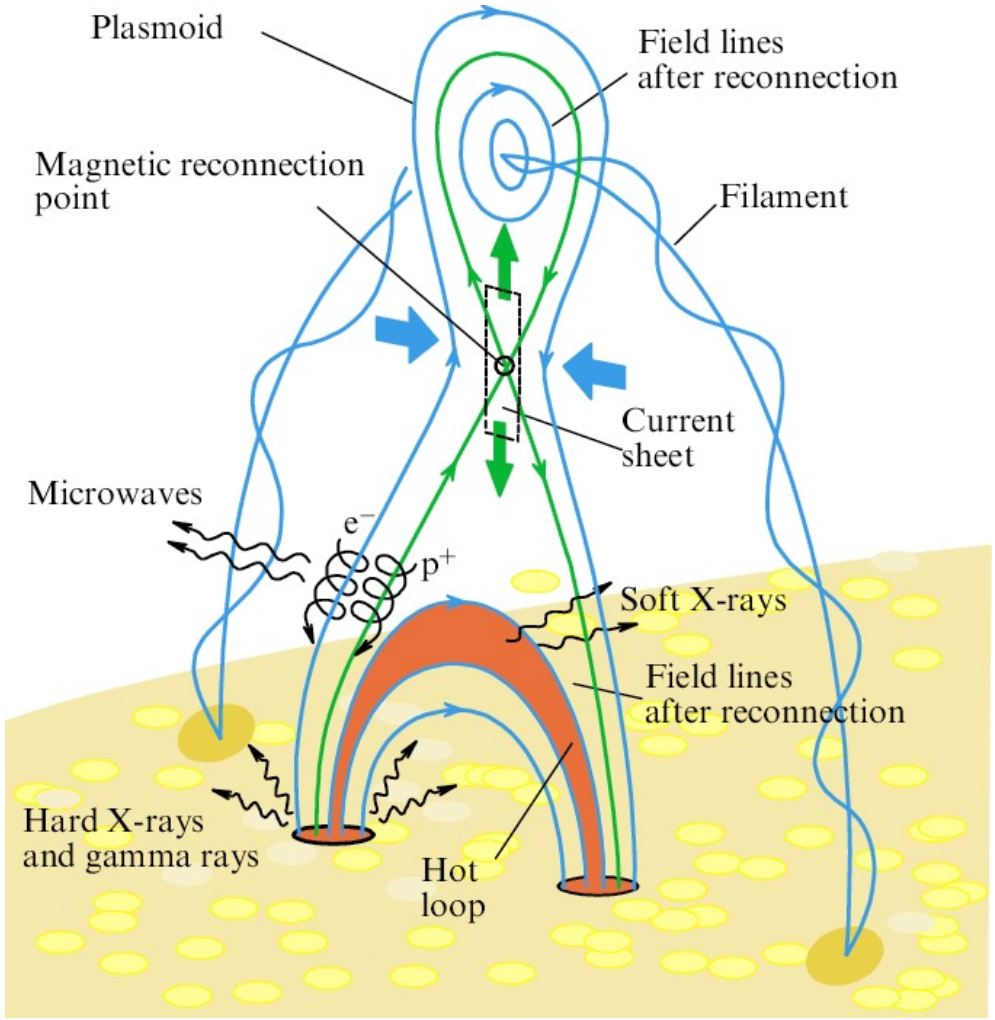
- Below the rupture
- Outbound and returning field lines reconnect into a much smaller hot magnetic loop anchored in the chromosphere
- Hot plasma consisting of
  - energetic electrons plus
  - hydrogen and
  - helium nuclei
  - stream down the reconnected field lines.
- These energetic particles are traveling at nearly the speed of light.

Nuclear Reactions Triggered



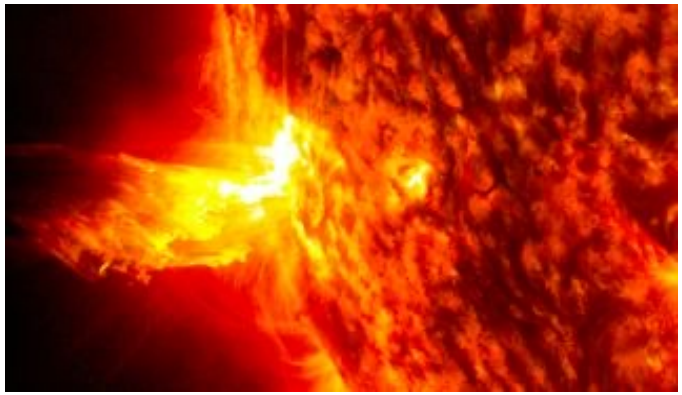
- Nuclear reactions are triggered as these particles crash into the upper chromosphere
- The nuclear reactions release a massive amount of energy in the form of
  - gamma rays,
  - x-rays,
  - visible light, and
  - radio waves.

Solar Flare – Above The Rupture Point



- Above the rupture, magnetic field lines also reconnect forming a plasmoid of hot
  - electrons plus
  - hydrogen and
  - helium nuclei.
- These particles are accelerated to high energy levels producing
  - High speed solar winds
  - Solar energetic particles
- The plasmoid rapidly expands into interstellar space as a coronal mass ejection (CME).

Ionospheric Storms



NOAA is interested in different things than we are:

Geomagnetic Storms - perturbations to the geomagnetic field.

Severe damage to power distribution systems, etc.

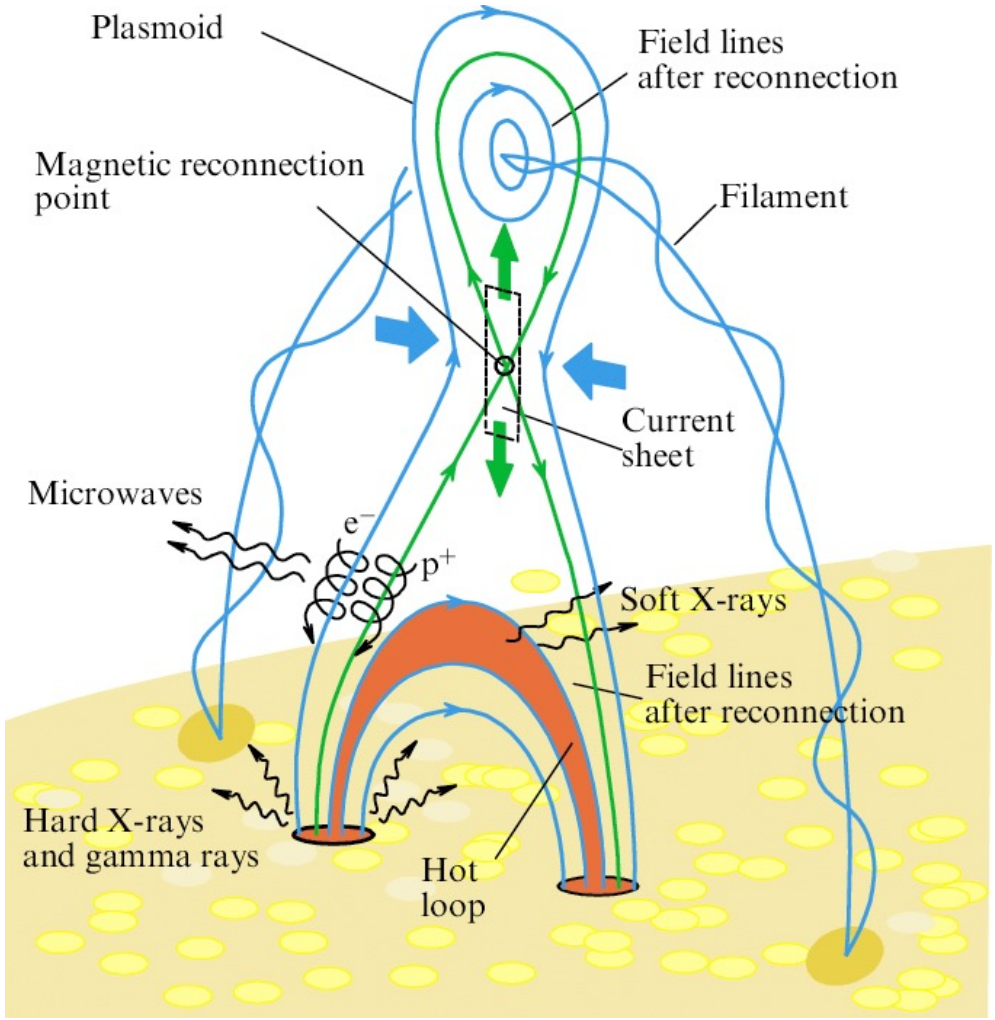
Solar (particle) Radiation Storms

Physical damage to spacecraft

Biological DNA damage, etc.

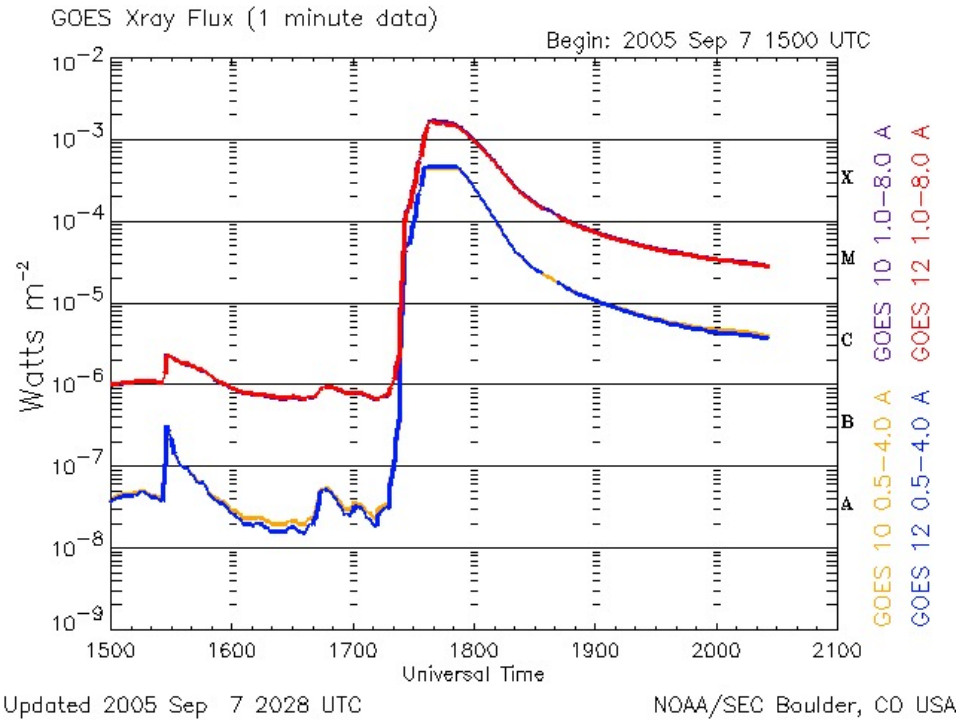
- Solar flares produce 3 types of Ionospheric Storms (what we are interested in)
  - X-ray Radiation Storms
  - High Energy Particle Storms
  - Solar Wind Storms
- NOAA's 3 corresponding space weather storm warning classifications are:
  - Radio Blackouts
  - Solar (particle) Radiation Storms
  - Geomagnetic Storms
- Space Weather customers include:
  - Spacecraft operators
  - Electric utility companies
  - Airlines
  - Many many others

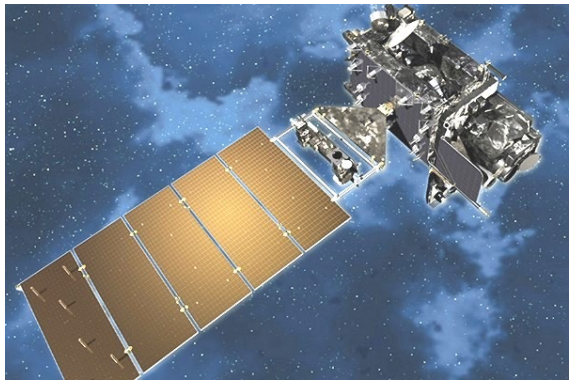
X-ray Radiation Storms (NOAA Radio Blackouts)



- The x-ray radiation released by a solar flare
- **Reaches Earth in a little over 8 minutes.**

Detecting X-ray Storms

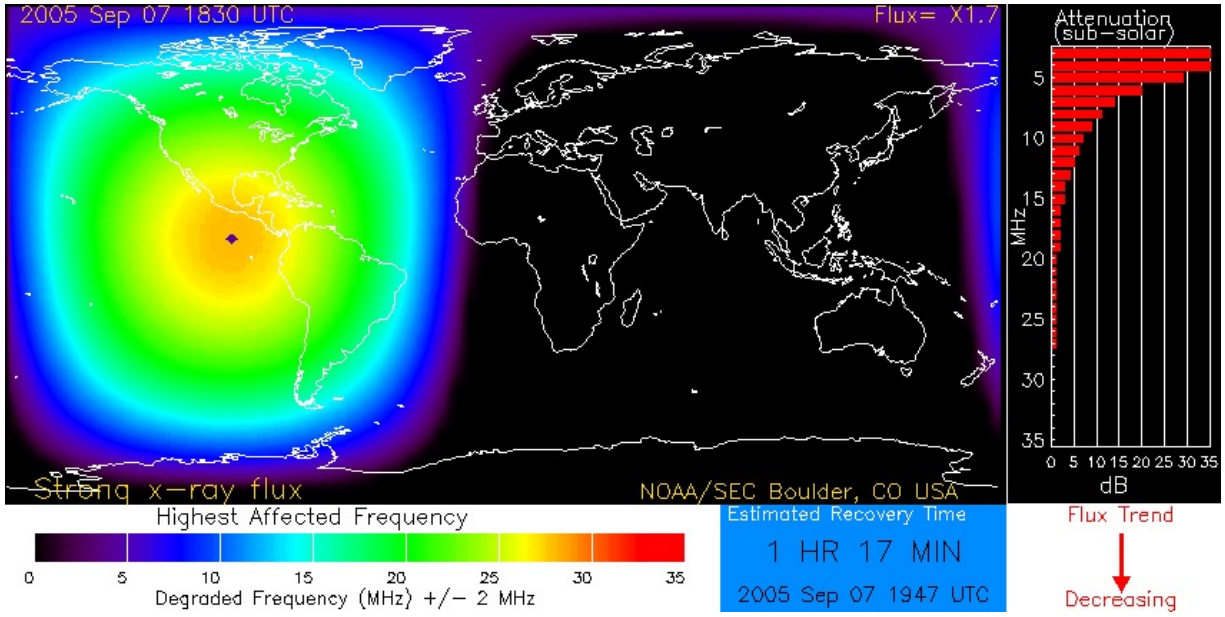




GOES satellite

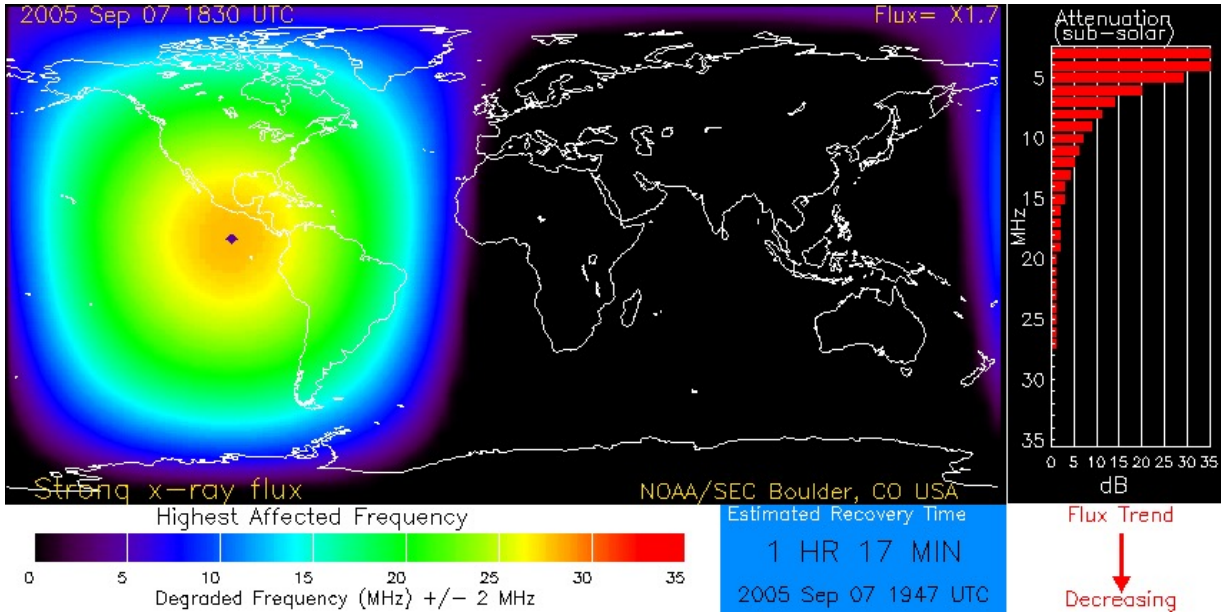
- GOES satellites orbiting Earth measure the intensity of x-ray radiation from a flare
- The vertical axis of the graph is similar to the earthquake Richter scale
- Each band (A, B, C, etc.) represents a x10 increase in X-ray radiation strength

X-ray Storms Heavily Ionizes D Layer



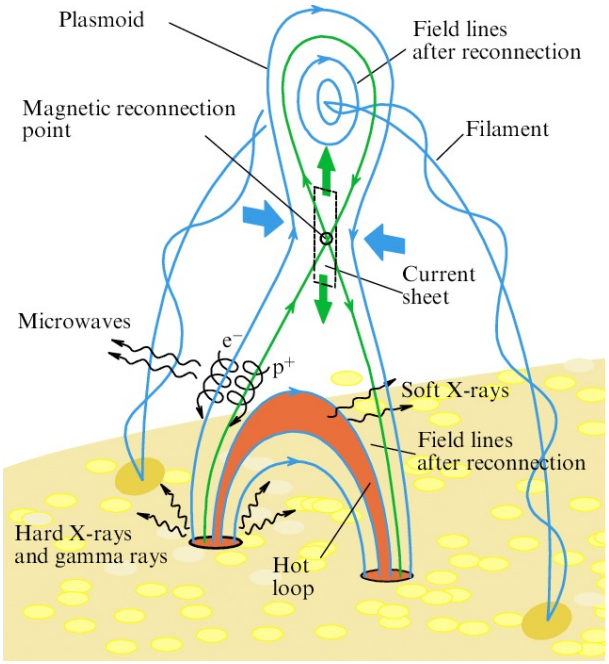
- The x-ray radiation heavily ionizes the ionosphere D – layer
- Causing extensive absorption of HF radio signals – **low frequencies hit hardest**
- Black diamond represents the Sun's location (local noon)
- Color bar represents the highest frequency bands affected
- Bar graph on right shows signal attenuation by frequency

Recovering From An X-ray Storm



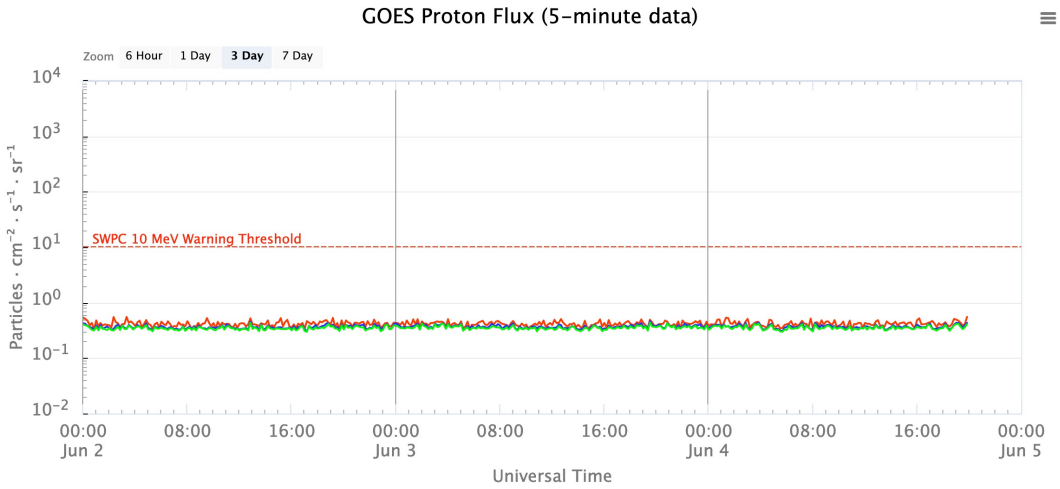
- The x-ray storm moves to the west as the Earth rotates eastward
- Look to the west for radio contacts if the solar flare occurs in the morning
- If it occurs in the afternoon, look to the east for radio contacts
- If the solar flare hits at noon, nothing you can do – go have a nice lunch
- BUT - look to the east for signals to recover as the storm moves westward

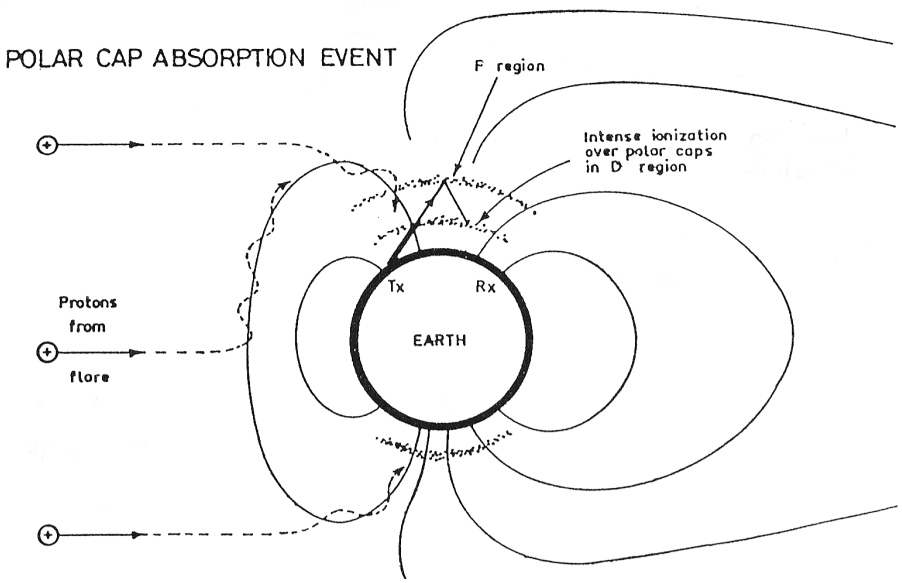
High Energy Particle Storms (NOAA Solar Radiation Storm)



- Above the rupture, magnetic field lines reconnect forming a plasmoid of hot fast moving
  - electrons plus
  - hydrogen and
  - helium nuclei.
- **These high energy Solar Energetic Particles reach Earth in 20 minutes to an hour**

Measured by GOES Proton Flux



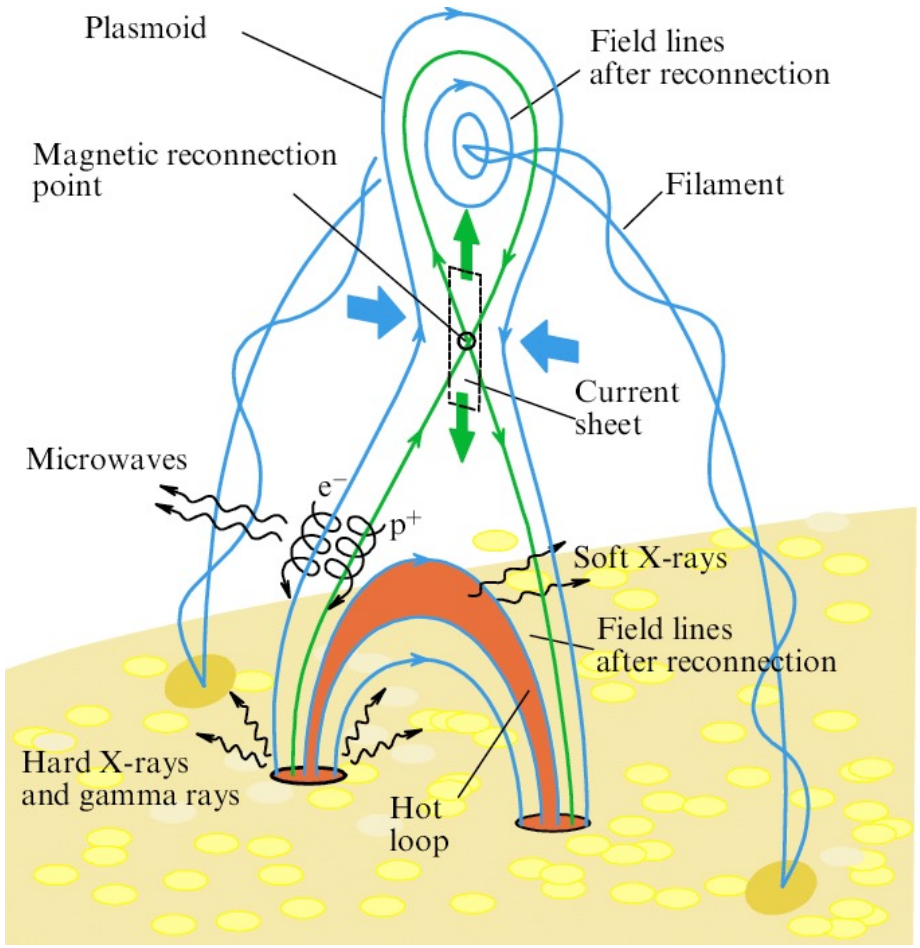


Polar Cap Absorption Event (PCA)

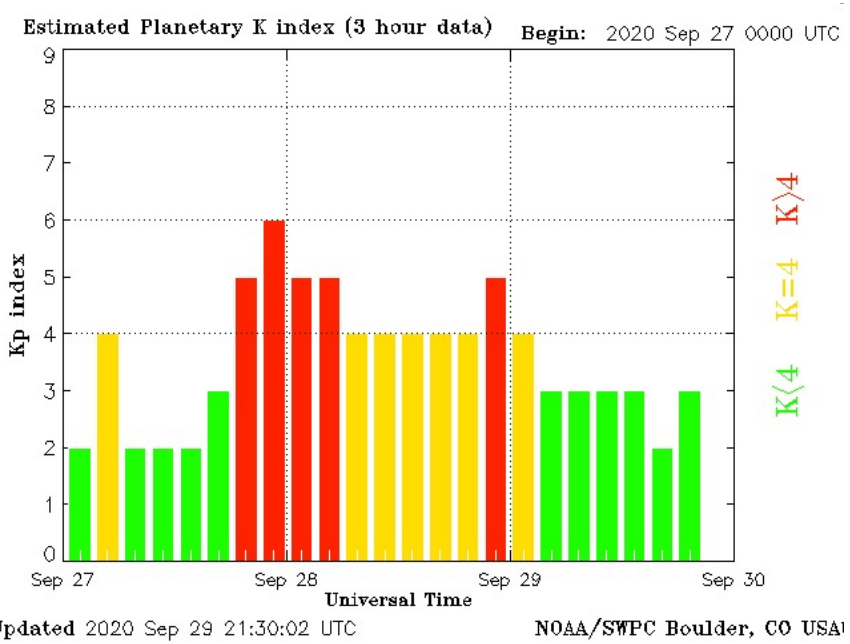
Relatively infrequent
less than 10 per year

- The Solar Energetic Particles spiral down Earth's magnetic field lines into the polar atmosphere heavily ionizing the polar ionosphere D-layer
- Extensive D-layer absorption of HF signals passing through polar regions
- This phenomena is known as a Polar Cap Absorption event (PCA).
- Lower frequency signals more heavily absorbed than higher frequency signals.
- A complete radio blackout can occur over the poles lasting for several days.
- **Avoid transpolar propagation paths following a large flare**

Solar Wind Storms (NOAA Geomagnetic Storm)

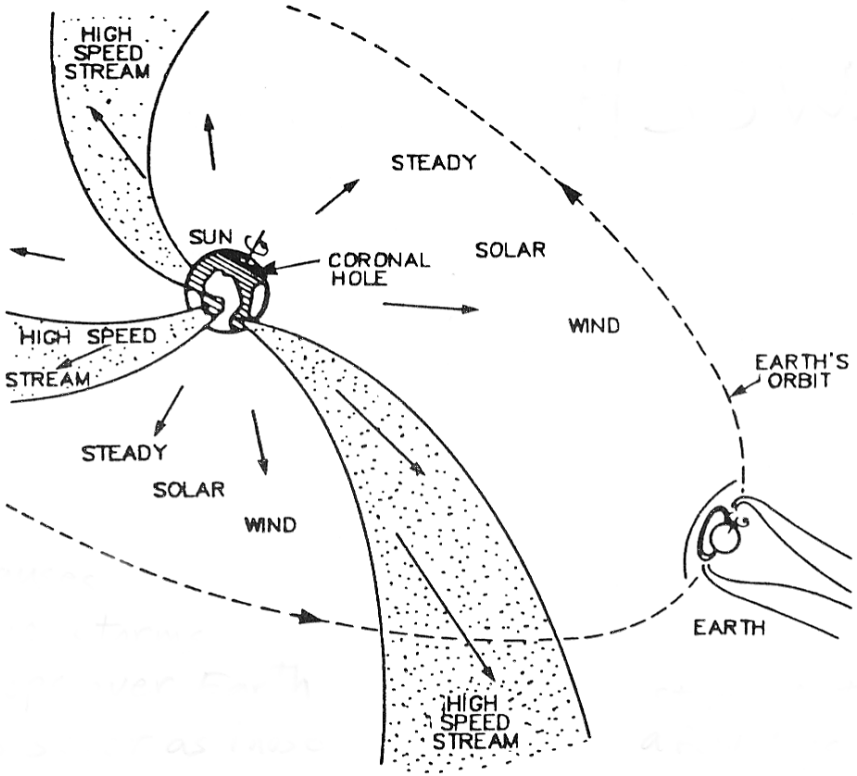


- The part of the original coronal loop above the rupture point is blown away as a coronal mass ejection (CME).
- Several billion tons of coronal material can be ejected



Kp indices measure geomagnetic storms
Also a good measure for ionospheric storms

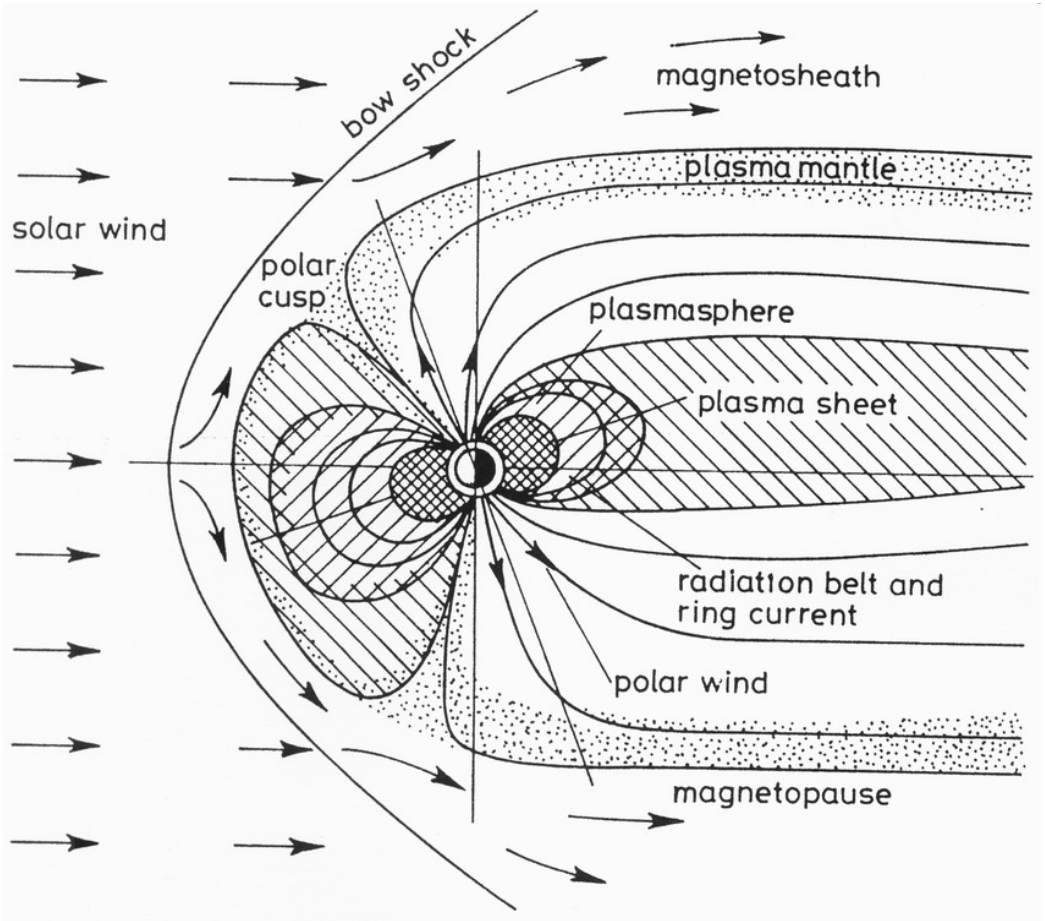
Solar Wind Storm Initiated By HSS Wind



HIGH SPEED STREAMS IN THE SOLAR WIND

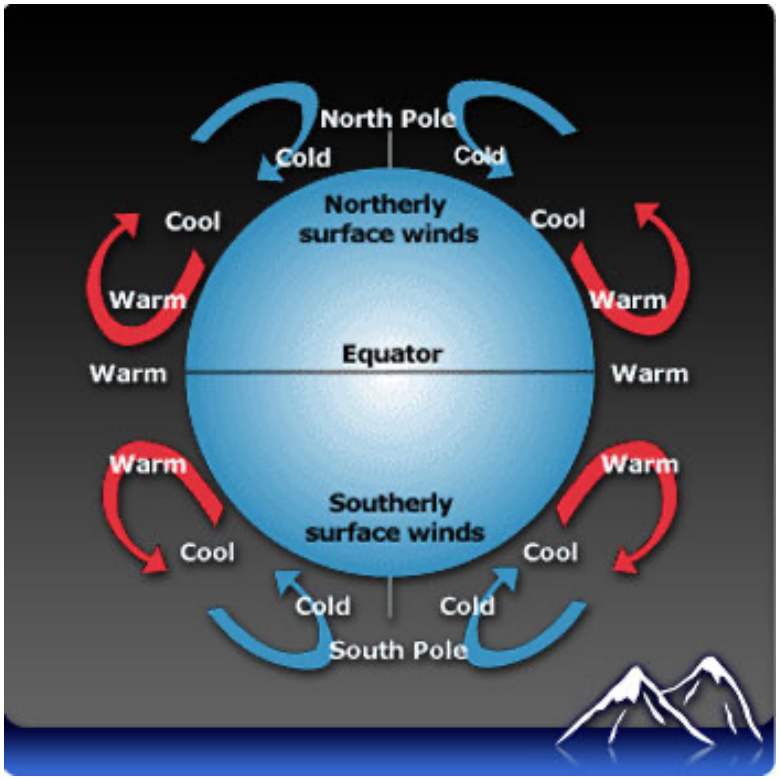
- The ejected material produces a high speed stream (HSS) solar wind
- The HSS wind spirals outward from the Sun
- The HSS solar wind, with its embedded interplanetary magnetic field (IMF**), reaches Earth in about two to four days.**
- When it arrives one of two things can happen.
- **If the IMF is northward, very little if anything happens**.

Solar Wind Storm – Southward IMF



- If the IMF is southward it connects to Earth's northward magnetic field pealing open polar region magnetic field
- Solar wind particles stream down into the polar region
- The charged particles (mostly protons) alter the ionosphere F_2 layer chemistry
- Collisions with neutral atoms & molecules heat the high latitude atmosphere
- Electron-ion recombination increases, critical freq drops
- Heating changes the circulation pattern of thermospheric winds.

Impact of Solar Wind Storms



We are impacted by

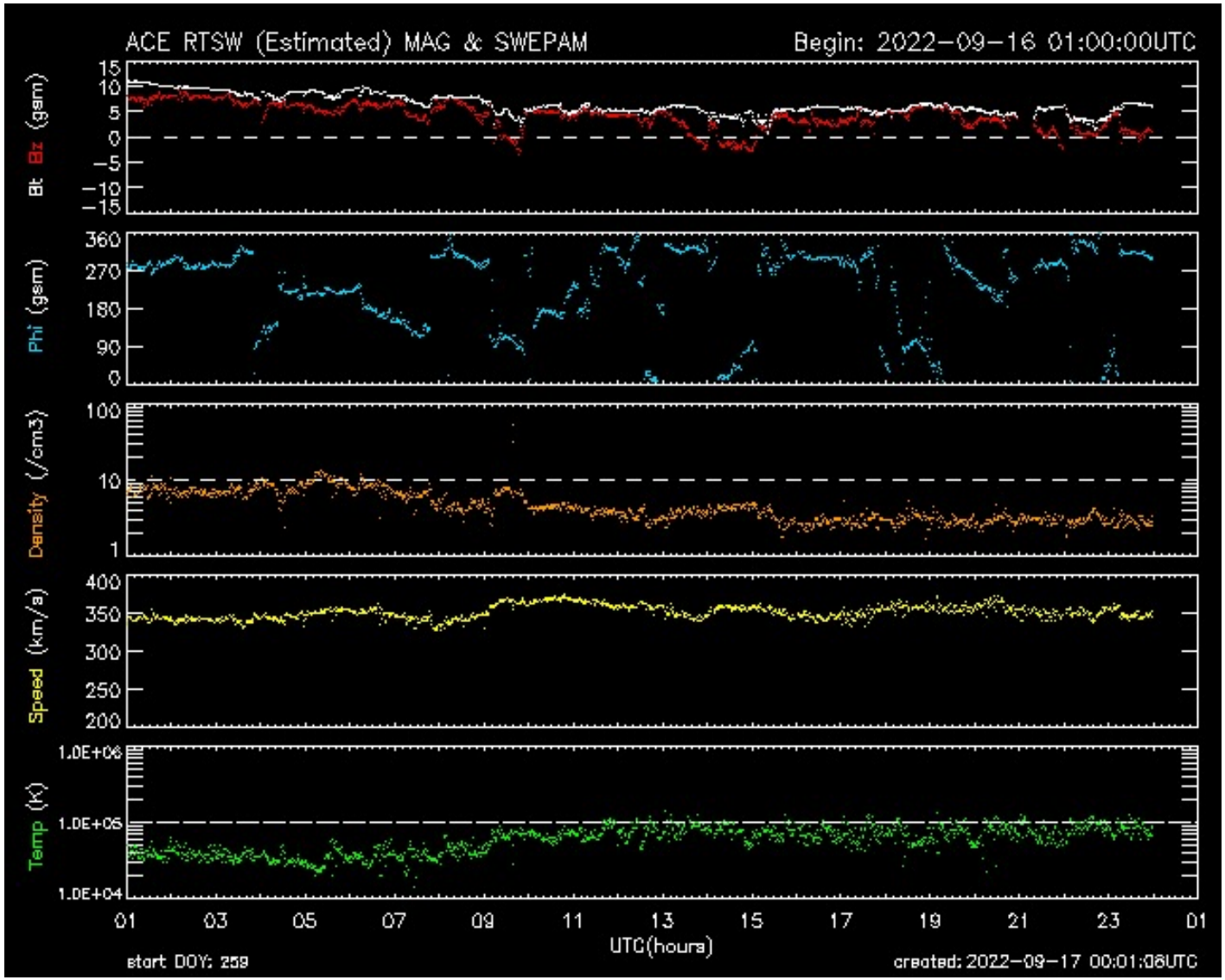
X-ray radiation storms

Solar wind storms

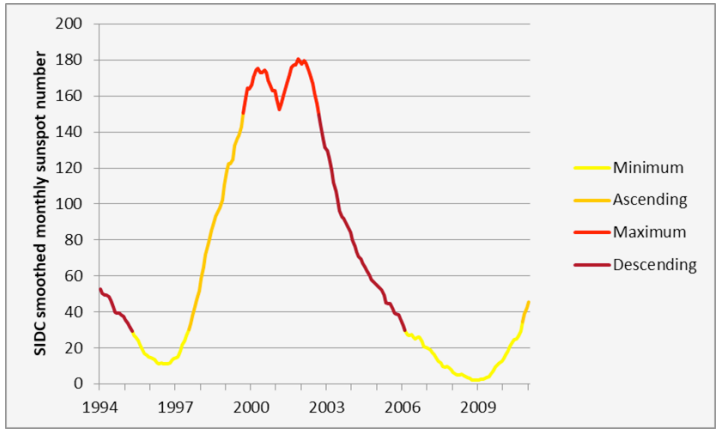
Not so much by PCA storms

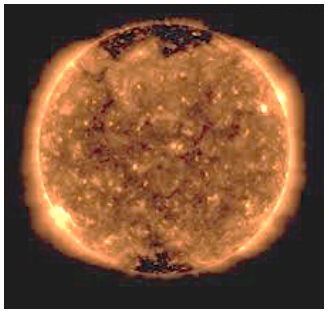
- Convection currents carry electron depleted polar ionosphere plasma down into mid latitudes
- F2 layer critical frequencies in mid and polar ionospheres drop by a factor or 2 or more
- Impacts higher HF bands more than the lower frequencies
- 20, 15, & 10 meter amateur radio bands affected the most
- These bands often disappear for a weak or more
- In addition to solar flares, prominences & coronal holes also produce solar wind storms

Solar Wind Data

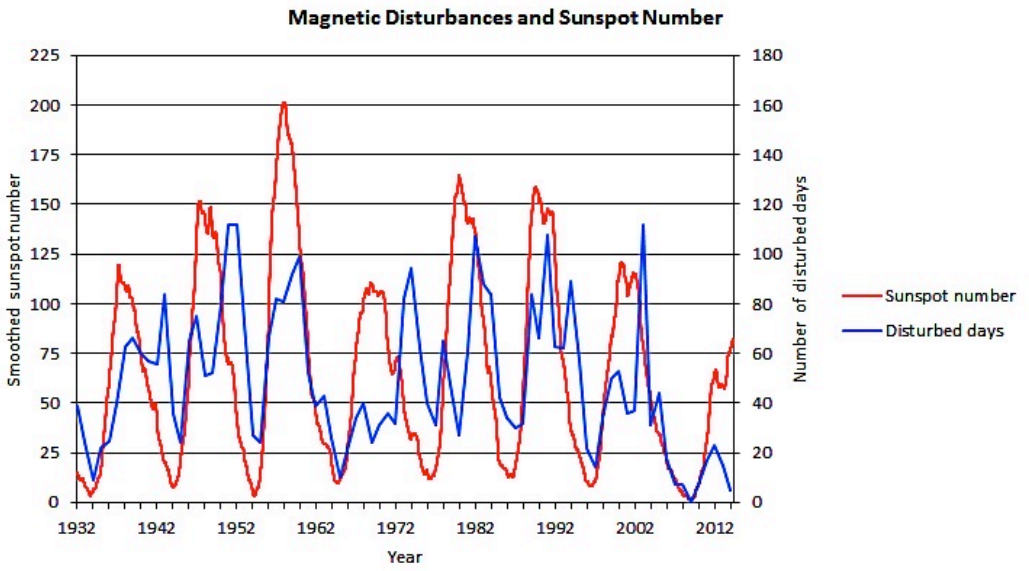


Descending Phase Of Solar Cycle



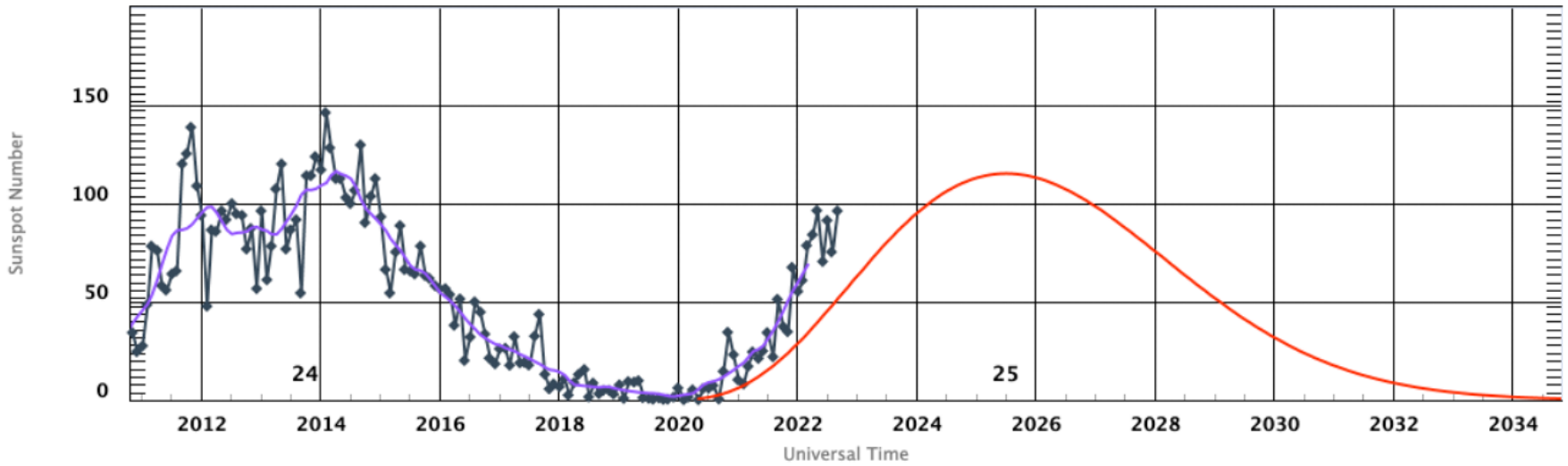


Coronal Holes



- Solar activity declines
- Sunspots begin disappearing
- Surprisingly largest number of solar wind storms occur during declining phase of solar cycle
- Occur typically 1 to 2 years after solar maximum
- Generally produced by coronal holes
- Usually NOT accompanied by X-ray and PCA storms
- But badly impacts 20, 15, & 10 meter operation

Conclusion of Solar Cycle 25



- Solar minimum expected to return around 2032
- Ending Solar Cycle 25