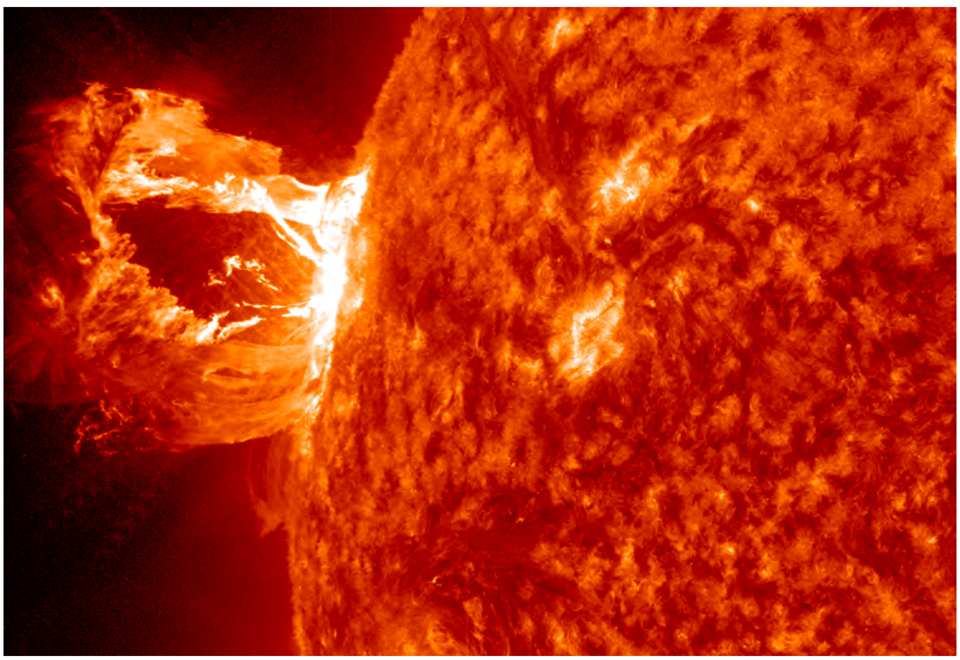
Chapter 5

The Active Sun



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5 The Active Sun

Other than the solar cycle itself, all of the phenomena that affect HF communications occur in the Sun's atmosphere. This is particularly true during solar maximum. These phenomena include

- Sunspots,
- Faculae,
- Plages,
- Prominences,
- Filaments,
- Coronal Loops,
- Solar Flares,
- Coronal Mass Ejections (CMEs),
- Coronal Holes, and
- Radio Noise.

5.1 Sunspots and Sunspot Groups

Sunspots, as we know, are black irregularly shaped blemishes on the Sun's surface. A number of sunspots are shown in Figure 1. Sunspots appear, increase in number, and then gradually disappear over the 11 year solar cycle. A solar cycle begins at solar minimum when few if any sunspots are present and the Sun's magnetic field is a "quiet" north – south bipolar field illustrated in Figure 2a. Increasing numbers of sunspots appear at a fairly rapid rate as the cycle progresses. The solar cycle reaches a maximum in roughly 3 to 6 years when a relatively large number of sunspots are visible. The sunspots then slowly disappear over the next 5 to 8 years reaching a minimum again at the end of the cycle.

Figure 1 Sunspot groups (credit: NASA Goddard Space Flight Center)

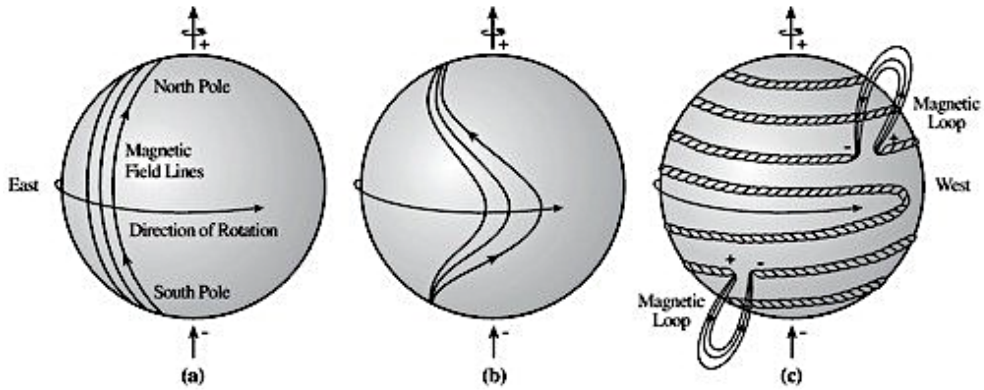


Figure 2 Magnetic field lines become wrapped and twisted around the Sun as the solar cycle progresses (credit: NASA's Cosmos – ase.tufts.edu)

A sunspot develops at a point where the Sun's magnetic field erupts through the photosphere (the Sun's visible surface) as shown in Figure 2c and Figure 3. A second sunspot occurs were the magnetic field plunges back into the photosphere. Notice that sunspots have magnetic polarities created by the magnetic field's direction of flow. The field flows out of a magnetically north (N) sunspot and into a south (S) magnetic spot. North and south are often represented as "+" and "-" respectively.

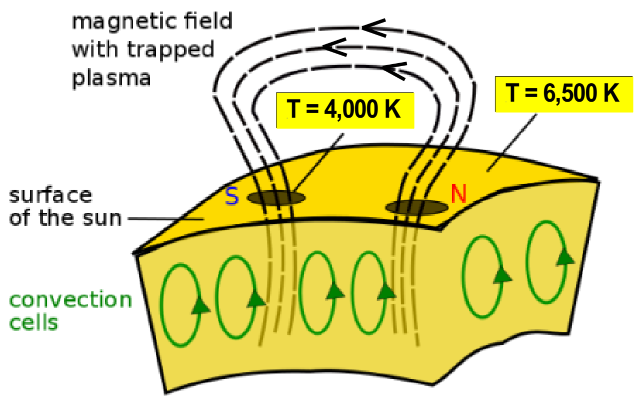


Figure 3 Formation of sunspots (credit: Sky Maps with Pierre Auger Data)

The peak intensity of the field emanating from a sunspot is in the neighborhood of 3,000 to 4,000 gauss. This field is so intense that it suppresses the upward flow of hot plasma below the sunspot location, causing the sunspot site to be over 2,000 degrees cooler than the surrounding photosphere. The sunspot's lower temperature is why it appears black in color.

The center of a sunspot is the umbra while the outer lighter colored region is the penumbra shown in Figure 4. The umbra is the lowest temperature (blackest) part of a sunspot. The temperature of the umbra usually ranges from about 3,800 to 4,100 degrees kelvin compared to 6,500 K at the base of the photosphere. The penumbra around the outer edge of the sunspot is warmer and lighter in color. It is characterized by large numbers of elongated dark and bright filaments that extend outward from the umbra. Out flows of material occur in the penumbra, beginning at the umbra, reaching a maximum speed of 2 – 6 km/s, and then dissipating outside the penumbra.

Sunspots can be huge. Large sunspots (including both the umbra and penumbra) can be 50,000 km or more in diameter. More typically, the umbra is around 10,000 km in diameter, about the same size as the Earth. The Earth's diameter is 12,756 km. Sunspots appear, last several days, and then disappear. Some sunspots may last for several weeks.

Sunspots are part of the Sun's photosphere and thus rotate with the Sun. In Figure 5 sunspots move from left to right as the Sun rotates. Sunspots that disappear around the Sun's right limb may reappear about 13 days later on the left side of the Sun.

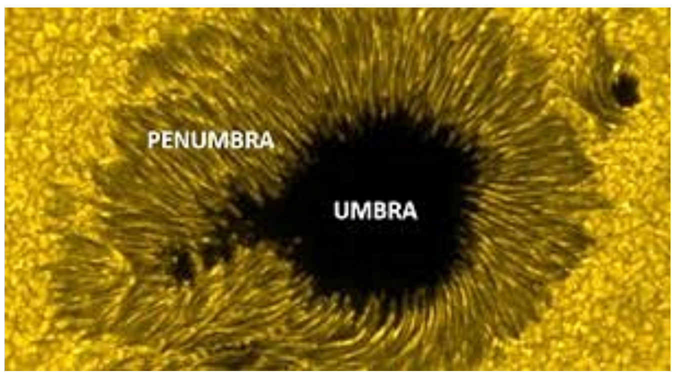


Figure 4 A closer look at sunspots (credit: spaceweatherlive.com)

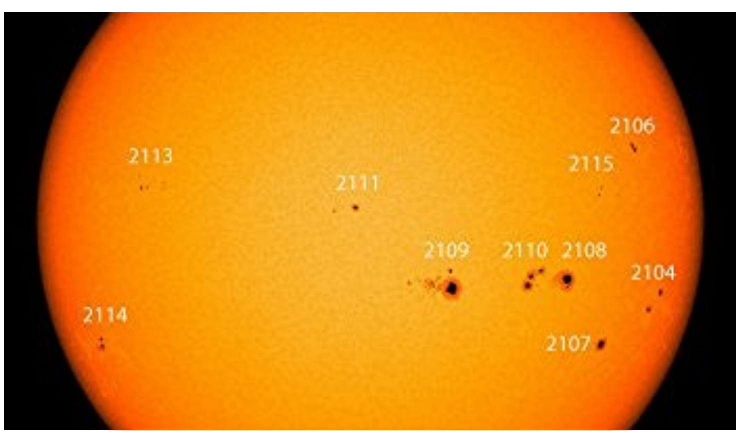


Figure 5 Sunspots on the face of the Sun (credit: NOAA Space Weather Prediction Center)

While isolated individual sunspots do form, most sunspots occur in pairs, or more commonly in sunspot groups aligned with the Sun's direction of rotation. A typical sunspot group is shown in Figure 6. The group rotates with the Sun so the large sunspots on the right are the leading spots while those on the left are the trailing or following sunspots.

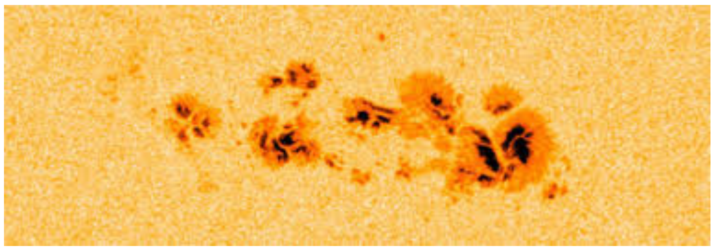


Figure 6 Sunspot Group (source: SpaceWeatherLive.com)

Sunspot groups tend to be complex varying widely is size and configuration. Considerable differences not only occur between groups but within the same group as it evolves.

There are important distinctions between leading and following sunspots. Leading sunspots are nearly always larger than following spots. Leading sunspots also tend to be more stable and have a longer life. Following sunspots seldom achieve long-term stability and often break up within a few days after appearing. Following sunspots also tend to be more irregular in shape often having only partial penumbras. 95% of sunspot groups that last long enough to make a second pass across the solar disk do so only with a single leading sunspot.

The leading and following sunspots have opposite magnetic polarities. If the leading sunspot has a north magnetic polarity, then the following sunspots must have south polarities. In addition, the leading sunspot always has the same magnetic polarity as the hemisphere in which it is located. The leading sunspot will have a north magnetic polarity in the Sun's magnetically northern hemisphere. Consequently, the leading sunspots in the northern and southern hemisphere have opposite polarities. The same is true of the following sunspots. Because of this, sunspot groups close to and on opposite sides of the solar equator cancel each other out resulting in no sunspots at the equator itself.

Sunspot groups are inclined with the leading sunspot being closer to the equator than the following spots. You can see this inclination in Figure 6. In this figure the leading spot is closer to the bottom of the picture, in the direction of the equator, than the other sunspots. The inclination is illustrated in more detail in Figure 7. The amount of inclination varies with latitude. Near the equator the inclination is usually only a few degrees. At higher latitudes the inclination may be as much as 15° .

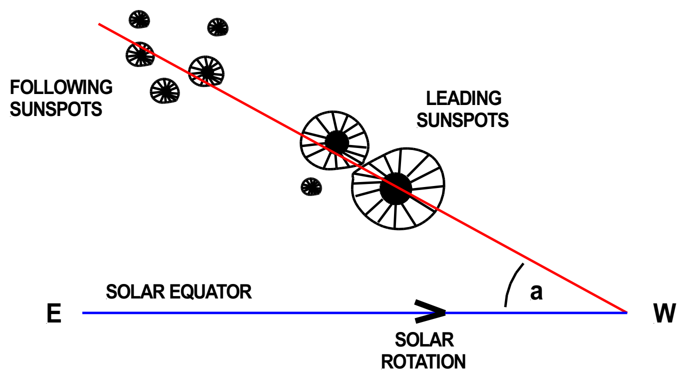


Figure 7 Inclination of a Sunspot Group (credit: author)

This inclination, coupled with the Sun's differential rotation, cause sunspots within a group to move with respect to one another. This movement tends to twist prominences and coronal loops that are rooted in sunspot groups. If the twisting is great enough it becomes one of the factors leading to a solar flare.

5.2 Faculae

Faculae, Figure 8, are bright hot depressions in the photosphere at locations where strong vertical magnetic fields emerge from the Sun's surface. However, a faculae magnetic field is not nearly as strong as that found in the umbra of a sunspot. Faculae are hotter than the surrounding photosphere which is why they appear bright. Within a faculae heat radiates from the walls of the faculae depression as well as from the bottom of the depression accounting in part for the faculae being hotter and brighter than the surrounding photosphere. A faculae depression is illustrated on the right in Figure 8. The faculae's brightness, as seen by an observer, originates within the region bounded by the dashed lines.

About 90% of faculae are associated with sunspots. Faculae typically appear several days before the appearance of sunspots and survive considerably longer. In terms of HF radio propagation, faculae are important because they are associated with hot Extreme Ultra Violate (EUV) radiation emitted by plages located in the chromosphere above the faculae.

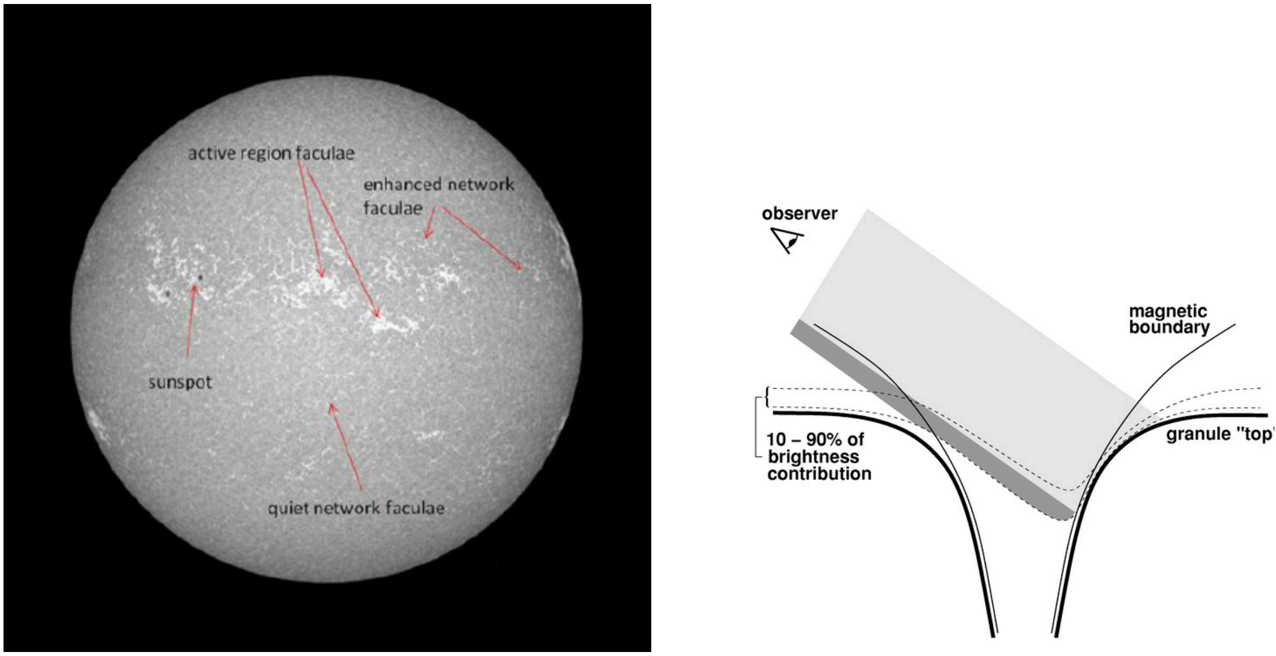
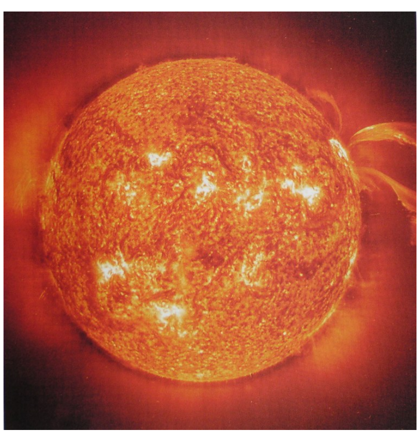


Figure 8 Faculae (source: P. Foukal, Heliophysics, Inc.)

5.3 Plages

Plages are hot bright irregularly shaped areas easily visible in the image of the chromosphere shown on the left in Figure 9. Plages are formed in the chromosphere by intense magnetic fields radiating out from faculae in the underlying photosphere. Like the faculae below them, plages occur in active sunspot regions of the Sun and usually form several days prior to sunspots in the area. Plages typically last long periods of time, longer than their associated sunspots, and emit copious amounts of EUV radiation responsible for ionizing Earth's upper atmosphere.



Plages shown in H alpha (H_α) light

Sunspots shown in intense light radiated by the photosphere

Figure 9 Sun's chromosphere shown in H alpha (H_α) light (credit: universitytoday.com)

While there is a strong correlation between sunspots and long-distance radio communications, it turns out that sunspots have little to do with HF propagation. Sunspots are far too low in temperature to generate the EUV radiation needed to ionize Earth's upper atmosphere. The required EUV radiation is primarily produced by plages. The problem is that plages can not be seen in the intense light emanating from the photosphere because the photosphere is too bright. But sunspots can easily be seen as readily apparent in Figure 9. Thus, sunspots become markers for plages. A large number of sunspots means a large number of plages, high EUV levels, strong ionization of the Earth's ionosphere, and good HF radio communications.

The EUV radiation responsible for ionizing Earth's upper atmosphere accounts for only 0.001% of the Sun's total energy output as illustrated in Figure 10. While the Sun's energy output remains incredibly stable over thousands of years, the Sun's EUV energy output is NOT stable at all! EUV energy varies considerably over the 11 year solar cycle. Consequently, the level of ionization in Earth's upper atmosphere also varies over the same time period. EUV energy output is greatest during solar maximum when there are large numbers of sunspots, and consequently large numbers of EUV emitting plages. EUV output is lowest during solar minimum when there are few if any sunspots and only a few randomly scattered plages.

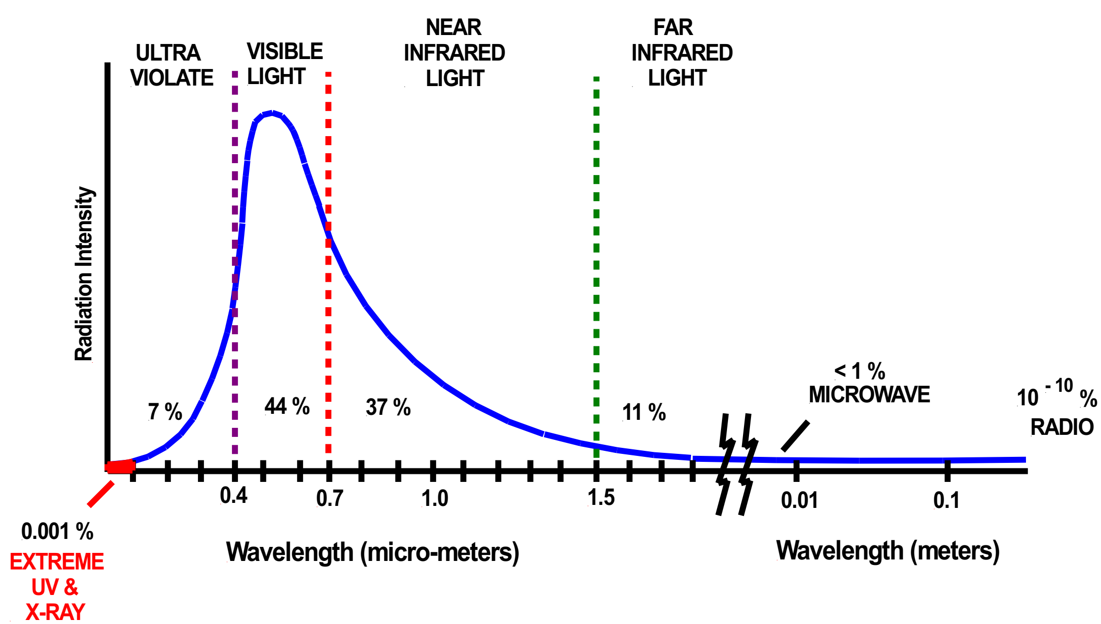


Figure 10 Sun's energy output (credit: author)

5.4 Prominences and Filaments

Prominences are large bright loops and curtains of relatively cool plasma suspended above the photosphere by strong arching magnetic fields. Prominences are often but not always associated with sunspot regions. A prominence occurring on the edge of the Sun is shown in Figure 11.

A prominence is formed by closed arching magnetic fields erupting through the Sun's surface with the two footpoints of the arch anchored in the photosphere. The magnetic fields inside a prominence are not smooth but are instead twisted and tangled by the turbulent and convective motion of the plasma at the base of the prominence.

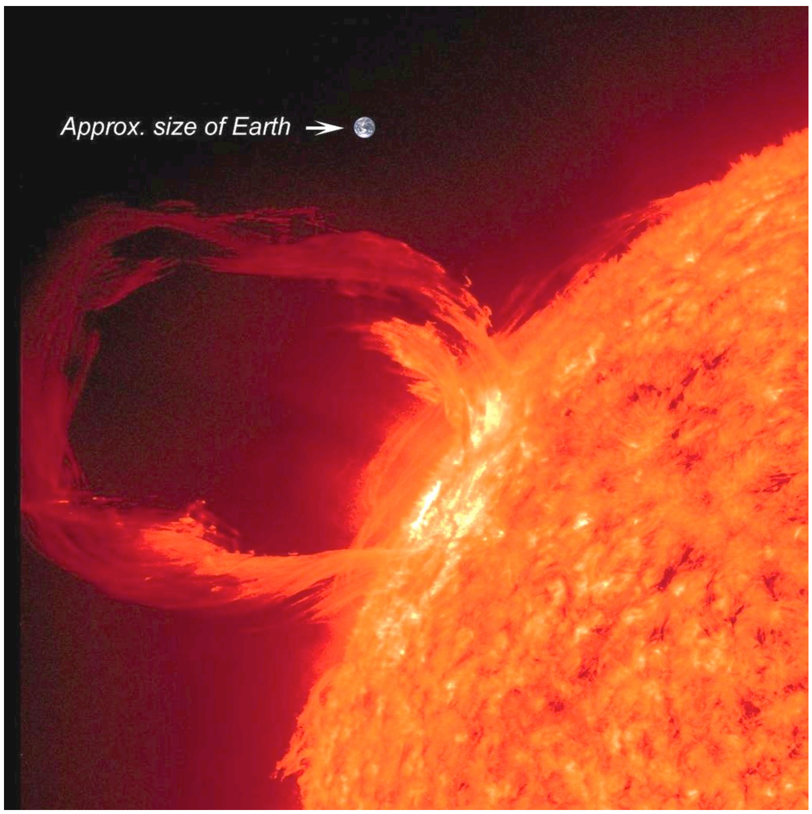


Figure 11 Active Region Eruptive Solar Prominences (credit: NASA)

The erupting magnetic fields carry with them electrically charged plasma of ionized gas and neutral hydrogen atoms. The charged plasma, often traveling at speeds of 40 km/sec, follow the magnetic field contours giving prominences their arching shape. Neutral hydrogen atoms are dragged along embedded in the plasma. Hydrogen atoms emit light in the Hα spectrum as their single electrons jump between valence states, giving a prominence its bright redish appearance. The strength of the magnetic field within a prominence typically ranges from 10 to 800 gauss, compared to the Sun's quiet bipolar field of around 1 gauss and intensities of over 3,000 gauss in twisted and knotted magnetic field lines. Temperature within a prominence is on the order of 7,000 degrees kelvin, much cooler and denser than the surrounding chromosphere and corona. A prominence typically has a plasma density of around 10^9 to 10^{11} particles per cm^3. Prominences usually extend through the chromosphere into the lower part of the corona and often last for several hours. In some cases, a prominence can remain in place for 2 - 3 solar rotations, each rotation being about 27 days. The stability of a prominence is due to the equilibrium between its opposing magnetic and gravitational forces. Disruption of this equilibrium causes prominences to collapse, sometimes catastrophically producing solar flares and coronal mass ejections.

Filaments and prominences are the same thing seen from different perspectives. A prominence appears as a high bright arching formation when viewed on the edge of the Sun against the black background of interplanetary space. When viewed on the face of the Sun, it appears as a dark erratic scare or filament, as illustrated in Figure 12. A filament is dark in appearance because it is relatively cool compared to the chromosphere below it.

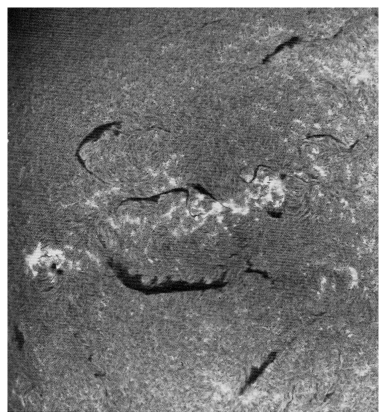
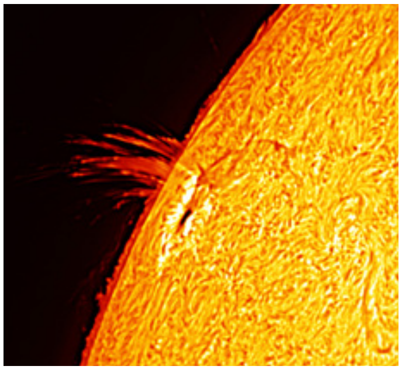


Figure 12 Filaments on the solar disk in H – alpha light. (credit: Big Bear Solar Observatory)

Prominences appear in various shapes and sizes. Prominences occurring in active regions of the Sun include eruptive prominences, like the one shown in Figure 11, spray prominences shown in Figure 13 that often precede a solar flare, and loop prominences that typically form after a flare. In active regions prominence material is often observed condensing and falling back toward the photosphere forming falling prominences like the one shown in Figure 13. Falling prominences are sometimes referred to as coronal rain.



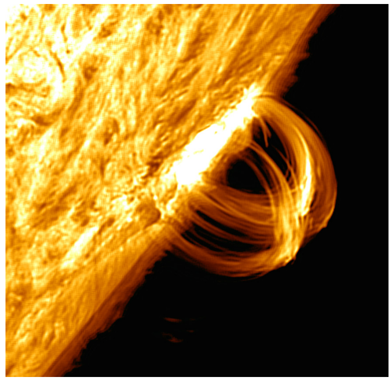


Figure 13 Spray Prominence Post Flare Loop Prominence Falling Prominences

Quiescent prominences are important because they typically are found far from active regions of the Sun. The hedgerow prominence shown in Figure 14 is a common quiescent prominence.

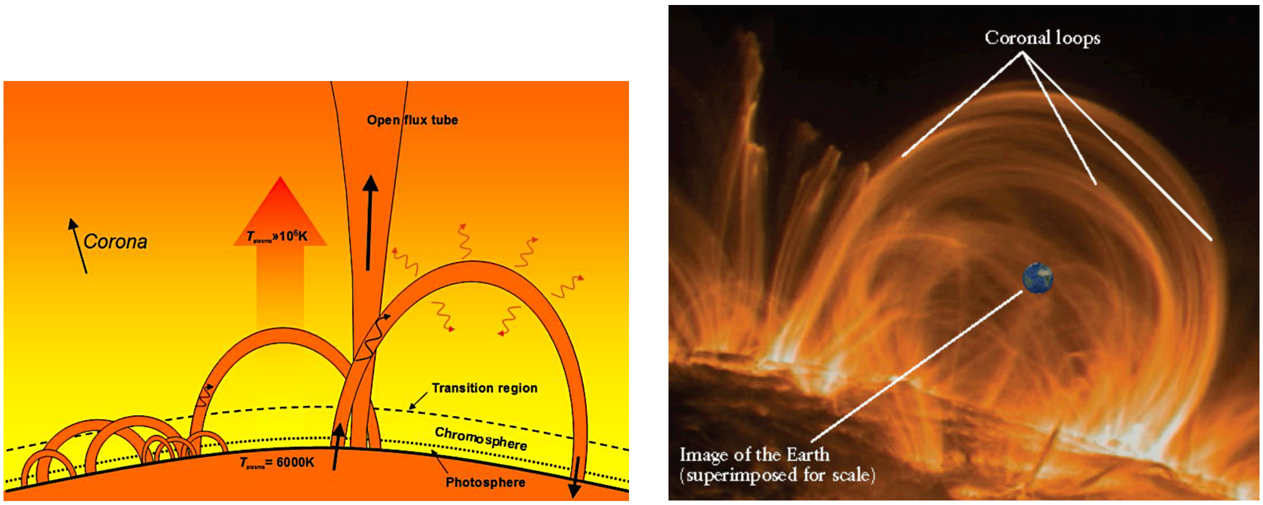
Figure 14 Quiescent hedgerow prominence (Source: Sky & Telescope)

5.5 Coronal Loops

Coronal loops are markedly different from prominences. Coronal loops are created by upwelling magnetic fields generated inside the Sun with their footpoints anchored in the photosphere, similar to prominences. But unlike prominences, coronal loops extend far out into the corona, as illustrated in Figures 15 and 16. A coronal streamer, illustrated on the right in Figure 16, is a large coronal loop that has been pinched together into an elongated point at its top by slow speed solar winds emanating from regions around the streamer.

These closed magnetic structures often form above sunspot groups in active regions of the Sun. They magnetically connect one region on the solar surface to another.

Magnetic field lines within coronal loops are smoother than in prominences.



Prominences Corona Loop

Figure 15 Prominences and Corona Loops (source: eclipse2017.nasa.gov/solar-prominences)

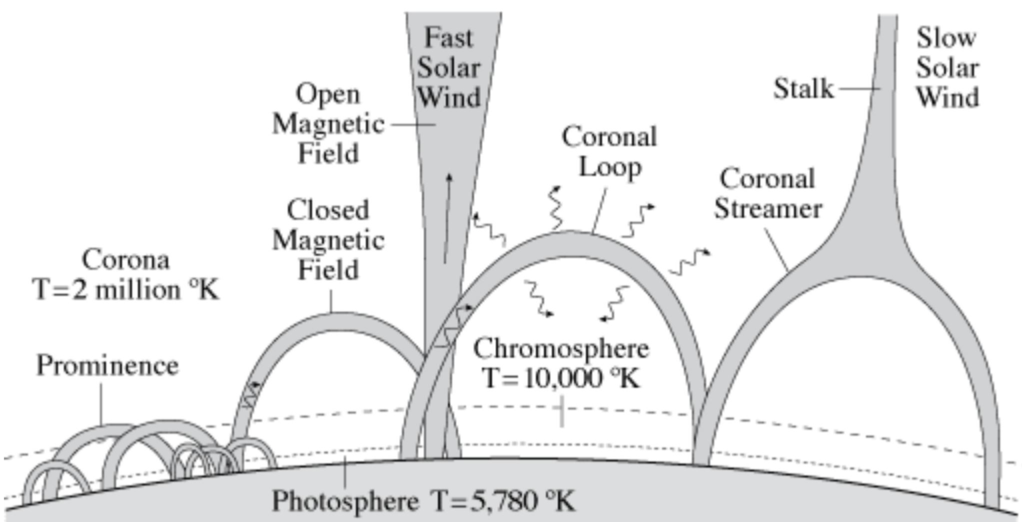


Figure 16 Prominences, Loops & Streamers (source: NASA's Marshall Space Flight Center)

The average plasma density of a coronal loop is about 100 particles per cm^3. In contrast, the plasma density in a prominence is on the order of 10^9 to 10^{11} particles per cm^3. Coronal loops are thus very thin and tenuous compared to prominences.

Plasma temperatures are much higher in coronal loops. The plasma temperature is over 100,000 ^oK, much hotter than the 7,000 ^oK plasma temperature in a prominence. At these high temperatures hydrogen atoms are all fully ionized, which means that each atom has lost its electron leaving behind only the atom's single proton nucleus. A nucleus can not emit light. Light is only emitted by the electrons of an atom as they jump between valance states. Consequently, unlike prominences, the light emitted by coronal loops does not come from its hydrogen atoms. Instead, the radiated light is the result of thermal emissions from its extremely hot plasma. The very hot plasma causes coronal loops to emit copious amounts of extreme ultraviolet and x-ray radiation. Some heavier ions in the plasma, such as ionized iron, still have a remaining complement of electrons that can emit light at discrete wavelengths. These emission lines are often used to determine the exact temperature and density of coronal loop plasma.

Coronal loops do not remain static in time. Driven by motion in the underlying photosphere and convection zone, coronal loops grow in size, twist and turn, and often catastrophically collapse as their magnetic field lines become tangled and twisted.

5.6 Solar Flares

A solar flare is a massive, sudden, explosive releases of energy stored in the magnetic field of a coronal loop. A flare occurs when the magnetic field lines of a coronal loop become severely stretched out and twisted concentrating enormous magnetic energy in a relatively small confined region of the loop. Continued stretching and twisting squeeze magnetic field lines closer and closer together. As this happens, energy in the confined region builds until it becomes so intense that outbound (+) and returning (-) magnetic field lines "short circuit" releasing a massive amount of energy in the form of a flare, a flash of light. In the process the outbound and returning magnetic field lines connect at the rupture forming a smaller lower energy magnetic loop, still anchored in the photosphere, that is only a tiny fraction of its original size. The top part of the initial coronal loop is blown off into interplanetary space.

A flare last from a few minutes to several hours heating the corona plasma in the vicinity of the explosion to well over ten million degrees. Extensive heating also occurs in the underlying chromosphere and in some cases in the photosphere. Large solar flares frequently occur during solar maximum and are the most powerful eruptions in the solar system.

A large solar flare occurring on Oct 2, 2014, captured by NASA's Solar Dynamics Observatory, is shown in Figure 17. This image of the chromosphere was taken in hydrogen-alpha (H_α) light. The flare is the large bright flash of light seen just above the chromosphere near the edge of the Sun. Below the flare a burst of solar material is erupting out into space. Flares are rarely visible in normal light because the photosphere is too bright.

Solar flares emit strong bursts of electromagnetic radiation, including gamma rays, X-rays, extreme ultraviolet radiation, visible light, and radio waves. In addition, huge quantities of high energy particles travel outward at high speeds from solar flares. Solar flares may also eject large clouds of coronal and chromospheric material, known as a coronal mass ejection (CME), into space and generate powerful shock waves. The shock waves propagate at high speed ahead of the CME material deep into interplanetary space seriously disrupting magnetic fields well beyond Earth's orbit.

The X-ray and EUV radiation from a solar flare reach the Earth in about 8 minutes. High energy particles can arrive in as little as 30 minutes. Shock waves and coronal mass ejections arrive in 1 to 4 days.

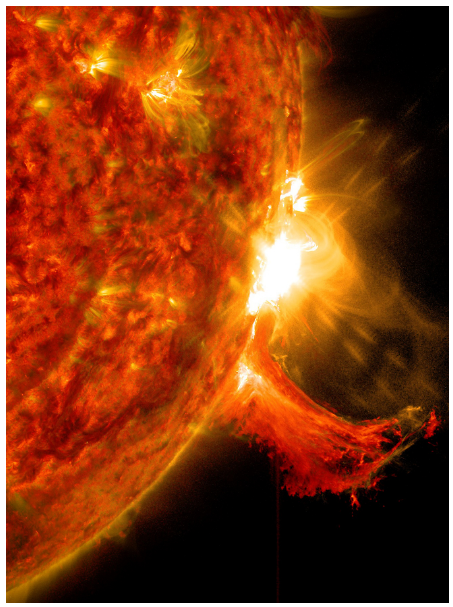


Figure 17 Solar flare (credit: NASA/SDO)

A coronal loop begins in Figure 18 as a strong arching magnetic field between a leading and following sunspot. As discussed earlier, sunspot groups are inclined with the leading spot closer to the equator than the following spots. Differential rotation of the Sun's surface coupled with convection zone turbulence cause spots in a sunspot group to move relative to one another, twisting the coronal loop illustrated in Figure 19 as it stretches out high into the corona. Continued stretching and twisting cause out going and returning magnetic field lines to come in close proximity at a region of the loop know as the x – point, so named because of it shape. This is shown in Figure 20. Tremendous magnetic forces build up at the x – point eventually causing the coronal loop to rupture at that point releasing enormous energy in a massive solar flare explosion.

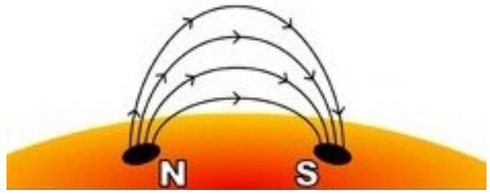


Figure 18   Emerging coronal loop (credit: UC Berkeley)

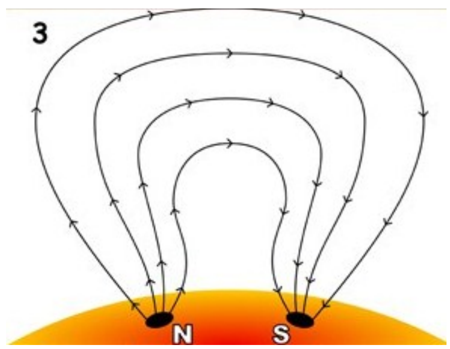


Figure 19   Coronal looping stretching out high into the corona (credit: UC Berkeley)

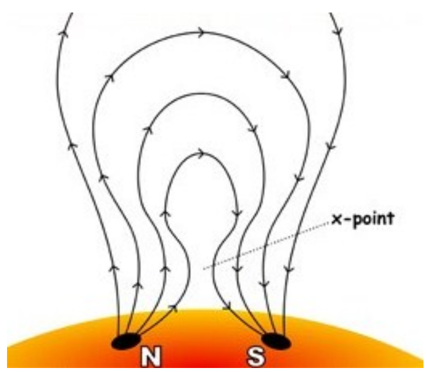


Figure 20   X-point forming (credit: UC Berkeley)

The outgoing and returning magnetic fields reconnect at the x – point (#1 in Figure 21) forming a smaller lower energy loop below the rupture – a process called magnetic reconnection. This smaller loop is rooted in the photosphere. A second loop forms above the rupture extending outward away from the Sun as illustrated in Figure 21.

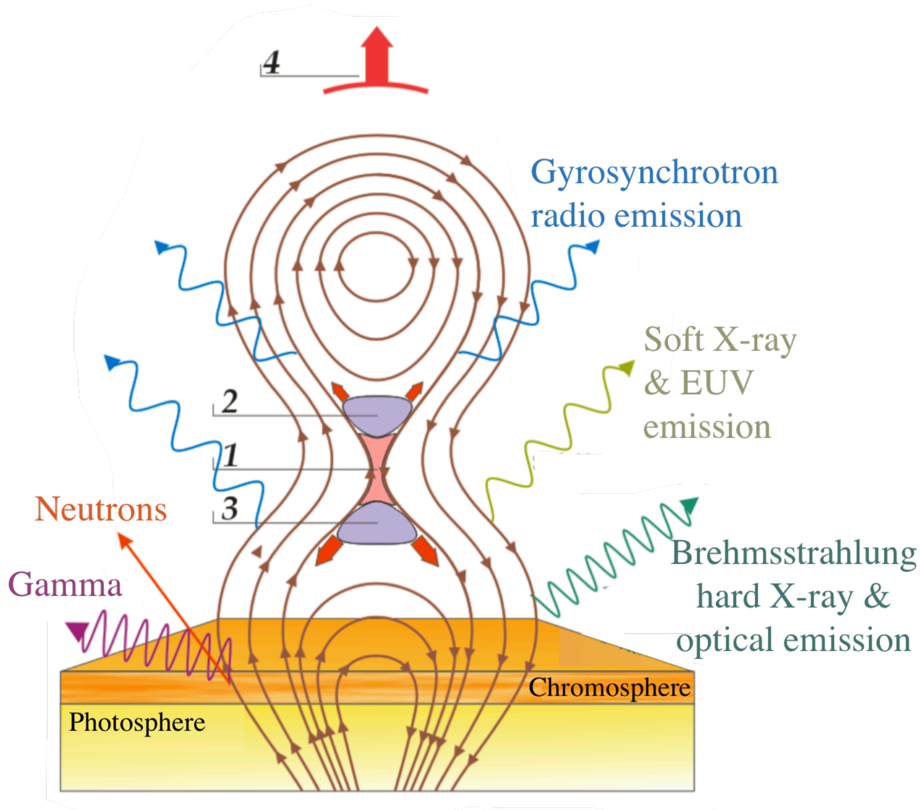


Figure 21 Structure of a solar flare (credit: ResearchGate)

Below the rupture hot plasma consisting of energetic electrons plus hydrogen and helium nuclei stream down the reconnected field lines (#3 in Figure 21). These energetic particles are traveling at nearly the speed of light. Intense heat is generated as they crash into the upper chromosphere. In some cases, the intense heat and relativistic speed of the collisions cause sporadic nuclear reactions to occur within the chromosphere releasing gamma rays and hard X-rays in addition to EUV radiation.

Above the rupture a hot plasma, also consisting of energetic electrons plus hydrogen and helium nuclei, stream outward along the upper field lines into interplanetary space (#2 in Figure 21). The kinetic energy associated with the rapidly expanding plasma creates shock waves (#4 in Figure 21) that propagate out from the Sun far past Earth's orbit.

5.7 Coronal Mass Ejections (CMEs)

A coronal mass ejection (CME) is huge eruption of coronal plasma, with its associated frozen-in magnetic field, that moves outward from the Sun into interplanetary space. CMEs vary widely in size, shape, and speed. Some look like loops, other like bubbles, and some are irregular in shape. Figure 22 is an example of a CME.

CMEs are often caused by solar flares associated with the catastrophic collapse of coronal loops as magnetic fields re-align and reconnect into lower energy states.

A CME can eject billions of tons of coronal material outward from the Sun at speeds typically ranging from 200 to 500 km/s. Some energetic CMEs can reach speeds of 3,000 km/s or more. A speed of 400 km/sec is nearly 1 million miles per hour. A shock wave is created when the CME travels faster than the background solar wind speed. The shock wave often accelerates charged particles ahead of it which can create intense high energy particle storms as the CME impacts the Earth. During solar maximum several CMEs of various sizes and shapes occur each day. At solar minimum one CME is typically observed every 5 days or so.

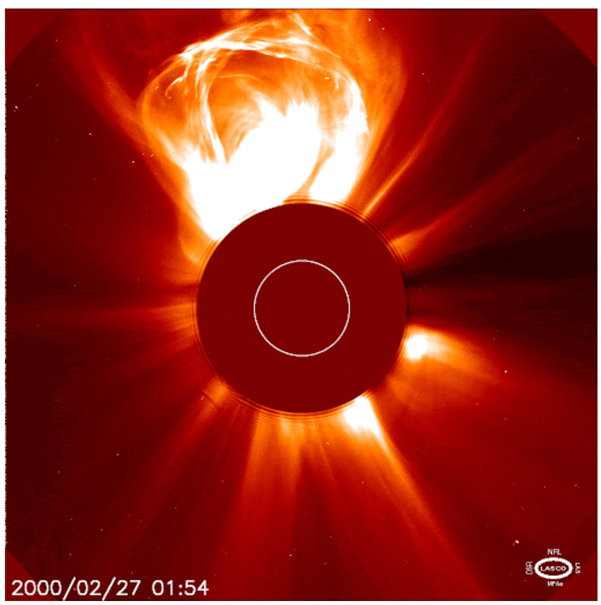


Figure 22 Coronal Mass Ejection (credit: www.astronet.ru)

Most CMEs are ejected outward from the Sun into the solar system away from the Earth. However, a CME launched in the direction of Earth can arrive in as little as 15-18 hours. Slower CMEs may take several days to arrive. A CME expands as it travels away from the Sun. A large CME can encompass nearly a quarter of the distance between the Sun and Earth by the time it reaches Earth.

Forecasters at the NOAA Space Weather Prediction Center (SWPC) monitor CMEs using imagery from orbital satellites to determine the likelihood of a CME impacting Earth. These satellites utilize an instrument known as a coronagraph to block out the Sun's photosphere so that the corona can be observed. A coronagraph in effect creates an artificial solar eclipse as shown in Figure 22. The NASA Solar and Heliospheric Observatory (SOHO) carries a coronagraph – known as the Large Angle and Spectrometric Coronagraph (LASCO). This instrument has two ranges for optical imaging of the Sun's corona: C2 (covers a distance range of 1.5 to 6 solar radii) and C3 (range of 3 to 32 solar radii). The LASCO instrument is currently the primary means used by forecasters to analyze and categorize CMEs; however, another coronagraph on the NASA STEREO-A spacecraft is an additional source.

The SOHO and Deep Space Climate Observatory (DSCOVR) spacecrafts both orbit the Sun at the L1 point approximately 1 million miles away from Earth. The L1, or Lagrangian Point 1, is the neutral gravity point between the Earth and the Sun and provides an uninterrupted view of the Sun.

A sudden increase in particle density, interplanetary magnetic field (IMF) strength, and solar wind speed at the DSCOVR spacecraft indicates an approaching CME shock wave and associated plasma cloud with its frozen-in magnetic field. This early detection provides a 15 to 60 minute warning prior to the CME impacting the Earth and potentially triggering sudden geomagnetic storms.

5.8 Coronal Holes

Coronal holes are dark areas seen in the solar corona when viewed in EUV and soft X-ray light. They appear dark, like those shown in Figure 23 , because they are cooler and less dense than the surrounding corona plasma.

Coronal holes can develop at any time and any location on the Sun. However, they occur most often at the solar north and south poles. Some of these grow and expand into the lower latitudes. Coronal holes can also develop in other regions of the Sun independent of the polar holes. In some cases, independent holes split off from polar holes. Coronal holes occur most often and last longer during solar minimums. In some cases, coronal holes can last for several solar rotations

Coronal holes are regions of open, unipolar magnetic fields that allow streams of relatively fast solar winds, known as high-speed streams, to escape into space. In fact, long-lasting coronal holes are a major source of high-speed solar wind streams that can buffet Earth for many days. Space weather forecasters analyze coronal holes closely because of their potential to disrupt Earth's magnetic field creating geomagnetic storms.

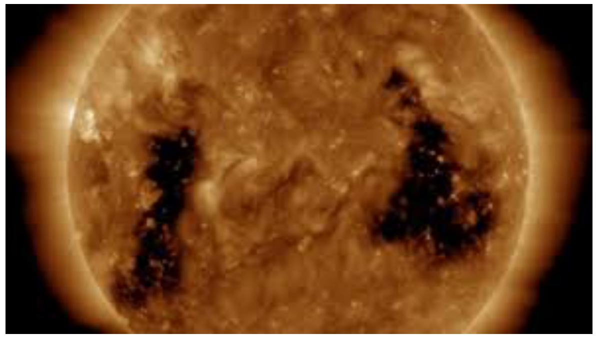


Figure 23 Coronal Holes (credit: NOAA www.swpc.noaa.gov/phenomena)

5.9 Solar Radio Noise

The Sun produces various forms of radio noise including:

1. Continuous background noise that is always present, and

2. Radio bursts that occur following flares and other disruptive events on the Sun.

5.9.1 Background Solar Radio Noise - SFI

The Sun produces continuous background radio noise generated by random collisions of electrons with heavier particles high in the chromosphere and lower corona. This radio noise is easily measured at a frequency of 2,800 MHz (10.7 cm wavelength) and is known as the Solar Flux Index (SFI). It has been consistently measured on a daily basis in Canada since 1947, first in Ottawa, Ontario and more recently at the Penticton Radio Observatory in British Columbia. It is one of the longest running records of solar activity. Because this radio noise originates in the Sun's chromosphere and corona, it tracks other important emissions that form in the same regions of the solar atmosphere. The Solar Flux Index correlates well with measured levels of solar X-ray and Extreme Ultra Violate (EUV) radiation. It also correlates remarkably will with sunspot numbers Figure 24. In addition, the Solar Flux Index is an excellent indicator of ionospheric conditions, including HF radio propagation through Earth's upper atmosphere. SFI numbers vary from a low of about 65 during solar minimum to around 225 at the peak of a solar cycle.

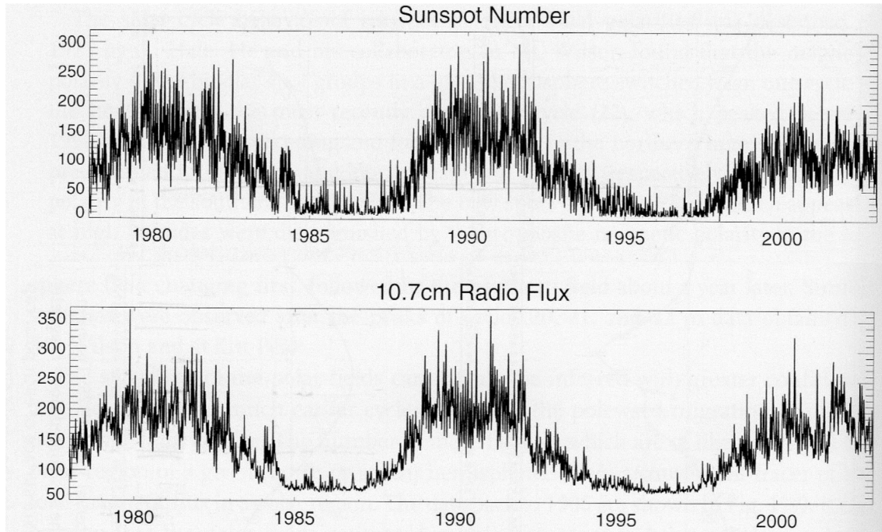


Figure 24 Radio Flux vs Sunspot Number (credit: G. deToma)

5.9.2 Radio Bursts

Figure 25 illustrates four types of radio bursts that commonly occur:

- Type I: Noise storm
- Type II: Slow drift burst
- Type III: Fast drift burst
- Type IV: Prolonged continuum

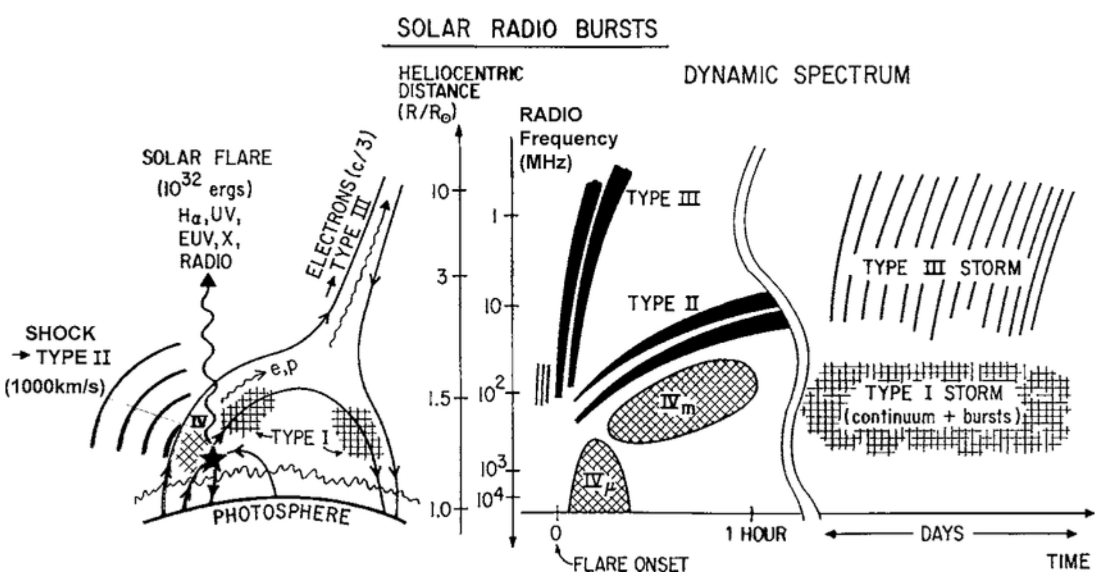


Figure 25 Solar radio bursts (Credit: ResearchGate)

The bursts are classified based on their spectrum, duration, and cause.

5.9.2.1 Type I Noise Storm

A Type I noise storm is a slowly varying increase in the Sun's background radio noise. The increase may be a million times greater than normal background conditions. Type I storms are strongly circularly polarized with a relatively narrow bandwidth typically ranging in frequency from 100 to 400 MHz. A storm can last from several hours to several days and may drift higher or lower in frequency as it evolves. Type I storms originate in the corona above active flare producing regions of the Sun.

5.9.2.2 Type II Slow Drift Radio Bursts

A Type II radio burst is an intense release of RF energy at frequencies below 200 MHz. The burst occurs in two discrete frequency bands consisting of fundamental and second harmonic frequencies. The two frequency bands drift lower in frequency at a rate of around 1 MHz per second over a period of 5 to 20 minutes. As shown in Figure 25, Type II bursts are generated by plasma disturbances (shock waves) that typically occur around the time of the soft X-ray peak in a solar flare. These disturbances expand outward from active regions of the Sun at 500 to 5,000 km/sec. The slow downward shift in frequency is the result of the disturbances traveling through regions of the corona having progressively lower electron densities.

5.9.2.3 Type III Fast Drift Radio Bursts

Type III radio bursts occur during the initial phase of solar flares and are the most common type of burst. They generate RF energy at frequencies from 50 KHz to around 700 MHz. They drift lower in frequency also, but much faster than Type II. The drifting rate for a Type III burst is around 10 - 20 MHz per second. Type III bursts are much shorter than Type II lasting only a few seconds to a few minutes. They are generated by plasma disturbances caused by energetic electrons accelerating outward from active regions of the Sun at speeds of 100,000 km/sec, as shown in Figure 25. The rapid downward shift in frequency is the result of these electrons traveling at high speeds through regions of the Corona with progressively lower electron densities.

A Type III noise storm is the decaying phase of a Type III burst that occurred earlier. A Type III storm is a low frequency long duration event as shown in Figure 25.

5.9.2.4 Type IV Prolonged Radio Bursts

Type IV radio bursts are quite different from Type II and III. They are generally considered the radio signature of coronal mass ejections (CME's) produced by flares and erupting coronal loops. They produce intense RF energy at frequencies from 100 KHz well into the microwave range.

However, the most studied Type IV bursts occur in the range from 10 to 100 MHz. Type IV bursts typically last from 10 minutes to an hour or more and are believed to be generated by gyro-synchrotron radiation from energetic electrons magnetically trapped in plasma clouds. These clouds typically accelerate outward from solar flares at speeds from a few hundred to about 1,500 km/sec.

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