

SOLAR ACTIVITY & HF PROPAGATION (With a “Flare” of Solar Physics)

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The Sun–Earth Interconnect

Since the late 1800s, it was noted solar activity affected telegraphic lines, and later, radio communications. However, there was no scientific proof for this link. From the 1920s onward, radio amateurs clearly correlated HF propagation and the MUF to the solar cycle. But again, there was no scientific proof. Astronomers and physicists knew there was a sun–earth connection, but without direct observational data, it remained an unproven scientific theory.

The scientific proof did not come until quite recently – basically, the space age – when we got our first look at the sun from outside our protective atmosphere. In the 1970s, the Voyager spacecrafts were the first to confirm the existence of the solar wind. It was not until Skylab that increases in radiation and the solar wind were linked to solar flares, and coronal mass ejections (CME) were first detected. The *sun-earth interconnect* finally became a scientific fact.

Since then, numerous satellites and ground based instruments monitor the sun and our geomagnetic field in realtime. Today, the radio amateur and QRPer has a wealth of solar information available via the internet that professional astronomers did not have a decade ago. This article, in part, describes how to interpret this internet data, and some of the terminology encountered in the daily reports and solar data from NOAA. Much of the solar physics in this article has been developed by astrophysicists in the past 15 years, and not yet available in other than scientific journals.

Solar Radiation

If the sun radiated as a thermal source only, the received brightness would vary directly with frequency – from ultraviolet and visible light down into the radio spectrum. This is called *Plank's black body radiation law*. Optical observations at different wavelengths does follow the black body radiation, proving the visible and optical wavelengths from our sun are thermally generated. However, *radio energy* does not follow black body radiation, proving the radio energy from our sun is being generated by processes other than heat, as shown in Fig. 1.

Solar Flux

Deep in the core of the sun is a massive thermo-nuclear reactor generating very short wavelength energy (gamma and x-rays). As this energy works its way to the surface of the sun, the wavelength gets elongated, or stretched, into the radio wavelengths, becoming the background radiation from the sun – called the *solar flux* (SF). It is measured at several observatories and reported daily by the National Oceanographic and Atmospheric Administration (NOAA) at their website: <http://www.sec.noaa.gov/today.html>. The solar flux is low during the quiet sun (SF <100) and elevated during the active sun (SF >100). In short, *the solar flux is a measure of the ionizing radiation from the sun*, and an indicator of the electron density of our ionosphere. The higher the electron density, the more reflective our ionosphere is to HF signals, and the higher the *maximum usable frequency* (MUF).

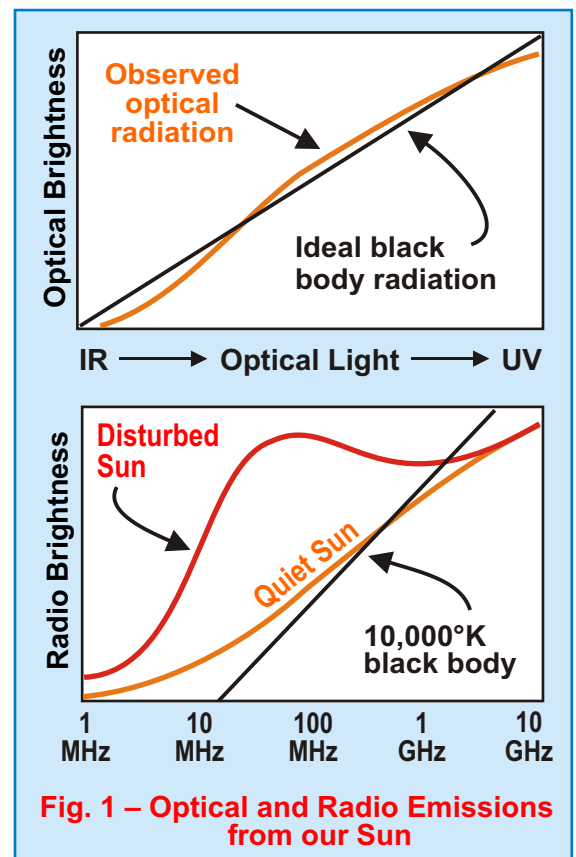


Fig. 1 – Optical and Radio Emissions from our Sun

The solar flux is measured at 2880 MHz (10 cm), a frequency not generally affected by solar flares, and one where our atmosphere is very transparent. Occasionally, a large solar flare will increase the 2880 MHz solar flux. NOAA will report this event as a *ten-flare*, indicating the 10cm solar flux value has been contaminated by a solar flare. Most people ignore the elevated solar flux from a ten-flare. However, it does indicate the earth was exposed to increased ionizing radiation from the solar flare – ionizing our E and F layers above the normal solar flux.

QRP Propagation Hint: QRPers should check the higher bands for openings for several hours following a solar flare, or a ten-flare event, due to the enhanced E/F layer ionization, possibly temporarily raising the MUF.

Ionization

The daytime ionizing radiation from the sun strips electrons away from their host molecules in our upper atmosphere. These *free electrons* increase the electron density of the ionosphere, stratify into layers, and called the D, E and F layers. The E/F layers are reflective to HF signals below the MUF, reflecting them back to earth for long distance communications. This is generally called *skip propagation*. The HF signals must also pass through the *D-layer*, the closest to the earth’s surface. This is called the absorption layer, since some of your HF signal will be absorbed by the D-layer – in fact, twice – going to, and coming back from the E/F layers for 2-6dB total path loss.

At night, solar radiation ceases and the free electrons *recombine* with their host molecules. The D-layer completely disappears and offers no signal loss. The E/F layers merge into a single layer, but remain reflective to HF signals. However, this combined layer has a lower electron density than daytime levels, lowering the MUF.

Astronomers call these ionization layers *plasma layers* and the *lowest* frequency that escapes into space the *plasma frequency, fp*. QRPers look at it just opposite – what is the *highest* frequency that *does not* escape into space? We call this the *maximum usable frequency* or *MUF*. In reality, the MUF and plasma frequency are exactly the same.

During the active sun, Earth’s plasma frequency is about 18 MHz (nighttime) to 30+ MHz (daytime), and during the quiet sun, varies from about 10MHz (nighttime) to around 20 MHz (daytime). Interestingly, the sun’s plasma frequency varies between 300–1000 MHz. The only time strong HF radiation escapes the sun is during a solar flare, and when it does, it is called a *solar storm*.

Sunspots and the Solar Cycle

The solar cycle was first realized by noting that sunspots “come and go” over a 7–11 year cycle. Sunspots are cooler areas on the the solar surface. More recently, sunspots have been identified as regions with *strong magnetic fields* called Alpha, Beta and Delta groups, as defined in **Fig. 2** and illustrated in **Fig. 3**. These *active regions* are carefully watched for possible flare activity.

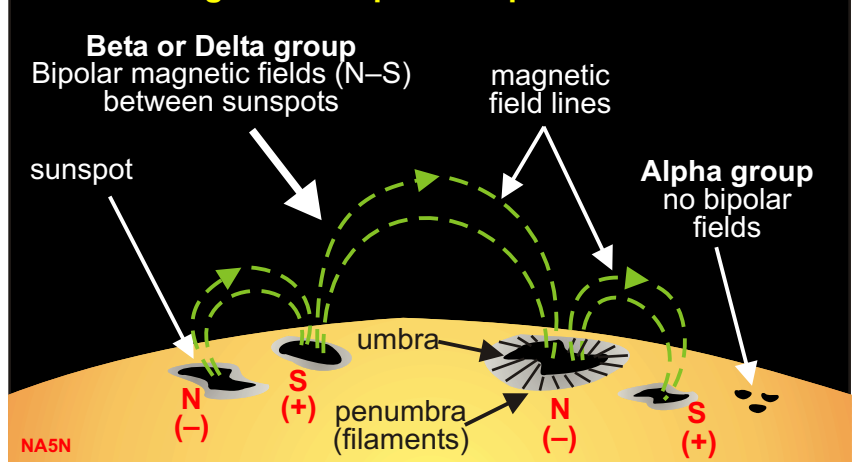
An *Alpha group* are sunspots with no bipolar magnetic fields, and seldom produce a flare. When bipolar magnetic fields (with N-S, or +/- polarization) develop between sunspots, it is called a *Beta group*. When a Beta group becomes particularly intense, with strong, bipolar magnetic fields between sunspots, it is called a *Delta group*. A *major flare alert* is issued by NOAA when a Delta configuration develops. A major solar flare will always occur from a Beta or Delta group, but, not all Beta or Delta groups will produce a flare.

Terminology seen in the NOAA reports will be the *umbra*, the central core area of the

Fig. 2 – Classifications of Sunspots/Active Regions

Sunspot Class	Description of the Active Region	Potential for Solar Flare Activity
ALPHA	Unorganized, unipolar magnetic fields	Little threat, but watched for further growth
BETA	Bipolar magnetic fields between sunspots	C class flares and possible M class flares
DELTA	Strong, compact bipolar fields between sunspots	High potential for large M or X class flares

Fig. 3 – Sunspot Groups Illustrated



sunspot, surrounded by an outer area with a filament structure called the *penumbra*. It is believed the filamentary structure of the penumbra is “painting” a picture of the magnetic field lines emanating from the sunspot. Often NOAA will report that a Beta group shows rapid growth in the penumbra. This means the magnetic field lines of the sunspot disturbance are rapidly growing, likely into a Delta group, becoming a high candidate for a major flare.

The Physics of a Solar Flare

Until recently, the physics behind a solar flare was not well known. They are extremely energetic events on the sun that can produce emissions across the entire spectrum – in the optical wavelengths, gamma and x-rays, down to the HF frequencies.

In many ways, a solar flare is very similar to a nuclear detonation. Imagine for a moment, you are about to witness the detonation of an atomic bomb, say the Trinity test in New Mexico on July 16, 1945. Sitting in the main bunker (see Fig. 4 and 5), you are surrounded by radio equipment to see what affect, if any, will occur to the HF and VHF frequencies.

At 5:29 am, the world’s first atomic bomb is detonated. You see a tremendous flash of light; the gamma and x-ray detectors are immediately triggered, and you hear deafening blasts of noise coming from your receivers. Light, ionizing radiation and radio waves are the first forms of energy to arrive at the bunker – *instantly*. They are traveling at *relativistic speeds* – the scientific terminology for the “speed of light.”

For the first few seconds, you see a huge, brilliant bubble of plasma and burning gasses. Everything inside this bubble is vaporized from the extreme temperatures (Fig. 6, $t_0+.05s$). After several seconds, the production of gamma and x-rays begins to subside. After about 10 seconds, the rising gas cloud begins to make the familiar mushroom shape (Fig. 6, t_0+15s). These are the hot burning gasses, electrons, protons and debris rising at about the speed of sound, or at *sonic* speeds. Along the ground, you can see a wall of debris being blown away from the explosion by the shock wave.

Several seconds after the detonation, you hear the thunderous boom of the air shock arriving. Several minutes later, the shockwave hits the bunker. This is a blast of hot wind traveling over 100 mph, carrying with it dirt, rocks and other debris carried along the way.

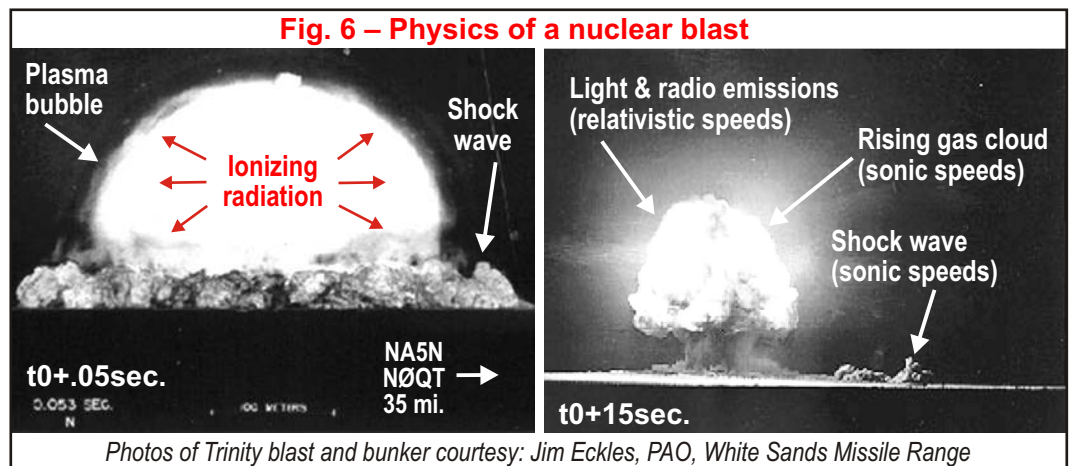
A solar flare is not much different. While the exact mechanism triggering a flare is not precisely known, it is believed that the strong magnetic field lines emanating from the sunspots becomes so strong, hot burning gasses from the sun are suddenly sucked out of the interior and carried along the magnetic field lines of the disturbance in a violent explosion. While the interior of the sun is exposed at the flare site, gamma and x-rays are allowed to escape, traveling outward at *relativistic* speeds. This explosion creates a shockwave, at *supersonic*



Fig. 4 – Trinity Site Main Bunker still exists today, minus the cables



Fig. 5 – Main bunker radio gear. Note Simpson VOM on the floor.



speeds, usually around 1,200–2,000 km/sec. Being well above the 350 km/sec. escape velocity of the sun, this shockwave carries some of the burning solar mass out into space.

This shockwave and rising gas cloud of solar mass, being ejected from the sun, is called a **Coronal Mass Ejection**, or **CME**. It is traveling outwards at **supersonic** speeds and could strike the earth if the trajectory and geometry is correct. Some of the burning mass gets caught in the magnetic field lines of the disturbance, forming an illuminated loop or halo, and called a **full-halo CME** as shown in **Fig. 7**.

The key point is a solar flare releases several major forms of energy that can effect VHF and HF propagation on earth:

1. Ionizing radiation, electrons and protons at **relativistic speeds** (arrives at earth immediately and for the duration of the flare event)
2. A **supersonic** shockwave riding along with the solar wind
3. Dense particles behind the shockwave (#2 and #3 arrives at earth 2-3 days after the flare event)

OPTICAL EMISSIONS

The emissions from a solar flare in the optical (visible) wavelengths are illustrated in **Fig. 8**. for a typical **short-duration flare** and the less common **long-duration flare**. An actual brightness plot of a flare, measured by photon counts from satellite instrumentation, is also shown. This is the optical evidence of the flare, which is actually very difficult to detect due to the normally bright surface of the sun. For this reason, flares are now determined by the x-ray radiation, detected onboard the GEOS, LASCO and SOHO satellites, not optically.

The optical properties of a flare are not particularly important to the ham or QRPer, other than indicating that other things are about to come!

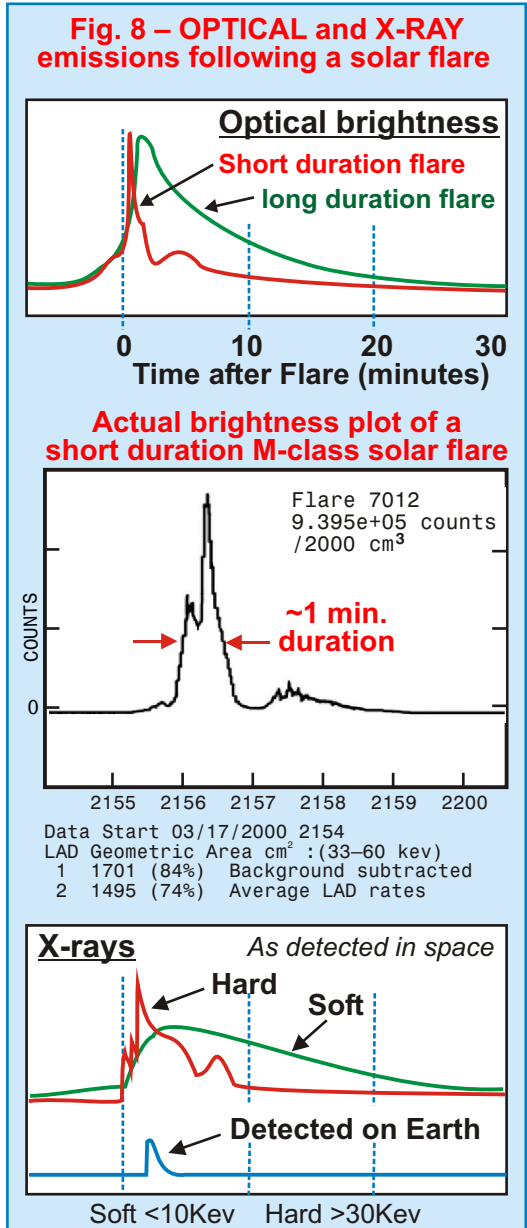
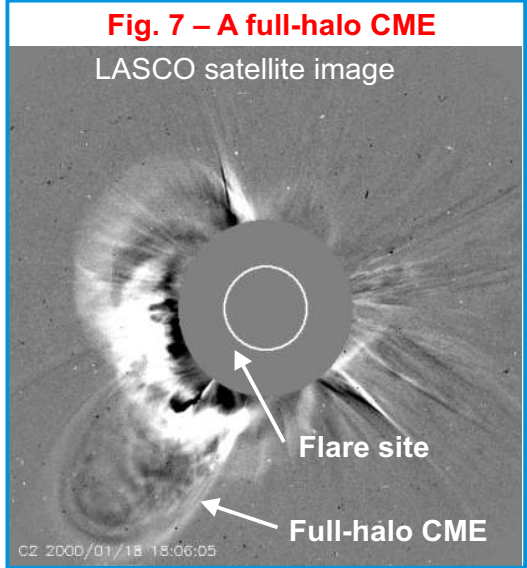
X-ray and Gamma radiation from a Solar Flare

Fig. 8 also shows the x-rays released from a solar flare. The **hard x-rays**, those >30 kev, is the ionizing radiation striking the earths atmosphere. The hard x-rays last only a minute or two, while the **soft x-rays** can persist from tens of minutes to over an hour – all the while showering the earth with ionizing radiation. X-rays from very large flares can also penetrate our atmosphere, all the way to the ground (a GLE, or ground level event). This will highly ionize the D-layer as well, causing an **HF radio blackout** for several tens of minutes following a major flare. This is fairly rare, occurring only a few times each solar cycle.

QRP Propagation Hint: If you're in a QSO when a major flare causes an HF blackout, it seldom lasts more than an hour. If you're working a contest, this hint could be useful. Take a break, but don't QRT!

These x-rays do provide extra ionization to the E/F layers for improved reflectivity and a higher MUF. Exploit the benefits of a solar flare.

QRP Propagation Hint: Good DX contacts are possible immediately following a solar flare until sundown due to the improved reflectivity (better signal-to-noise ratio for QRP signals) and the higher MUF opening the higher bands – especially during the solar minimum years.



Radio Emissions from a Solar Flare

The *microwave radiation* from a solar flare (**Fig. 9**) is similar to the ionizing radiation. It can produce powerful radio energies for several minutes following a flare, sometimes disrupting satellite and VHF communications. Radio telescopes use 2–10 GHz (S,C and X band) to make maps of the fine structures of the solar flare. 1.4 GHz, the spectral line of hydrogen (L band), is also mapped to show the intensities of local hydrogen and HII during a flare. This reveals the amount of ionization, and recombination near the sun’s surface. This is interesting from a science viewpoint, but not necessarily for ham radio.

For the radio amateur and QRPer, the real interest lies in what happens to the *HF bands*. Radio emissions from a flare can cause noise bursts, buzzing sounds, sudden QSB, continuum noise, and occasionally, a temporary HF blackout. After about 30 minutes following the flare, HF noise levels and propagation return to normal.

QRP Propagation Hint: The most important thing to remember about a solar flare is this: the HF effects are generally *only for the duration of the flare event* (20-60 minutes) and seldom effect frequencies <10 MHz.

The most damaging effects of a solar flare is actually the arrival of the shockwave 2-3 days later, triggering a geomagnetic storm. This is discussed beginning on the next page (Geomagnetic Storms).

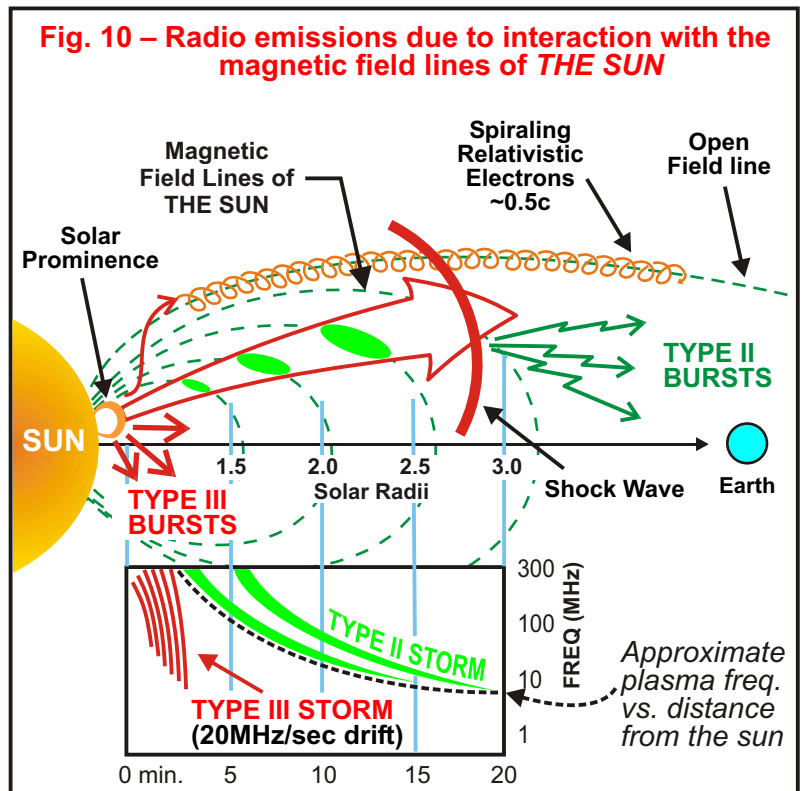
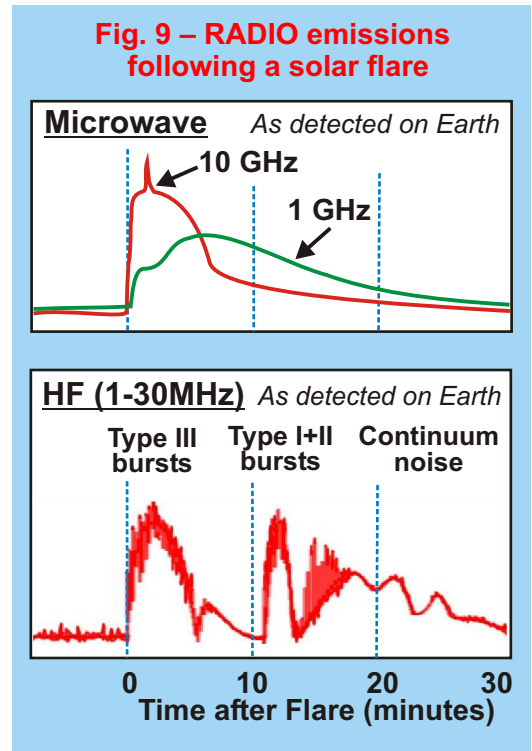
The following details of a solar storm is offered for completeness only. This is relatively new solar physics theories, and presented for those so interested, as the information is currently available only in professional astrophysical journals, and certainly not in amateur publications.

Radio Emissions due to the Electrons

The first radio emissions to arrive on earth following a flare is the bursty **Type III storm** occurring for the first 5-6 minutes following a flare. These are *relativistic electrons* released by the flare traveling through the *sun’s magnetic field* (**Fig. 10**). The radio emissions begin around 300 MHz and drift downward in frequency at about 20 MHz/sec.. They sound like ignition noise from a fast running engine, or sometimes a “buzz” as they sweep past your frequency. Seldom will these bursts be heard below 10 MHz. Some of these electrons migrate and travel along the open field lines in a spiraling motion, still about the speed of light, producing *continuum noise* (wideband) from 10–300 MHz.

Radio Emissions due to the Shockwave

As the *shockwave* travels through the *sun’s magnetic field lines*, electric currents and bursty radio emissions are generated by the dynamo effect, called a **Type II storm**. The sun’s plasma frequency becomes lower at greater distances. Therefore, as the shockwave travels away from the sun, the bursts are heard at lower and lower frequencies on earth, as shown in **Fig. 10**. This is important to astronomers. By measuring the time it takes for the bursts to drift from one frequency to a lower one, the velocity of the shockwave can be determined.



Both Type II and Type III sweeps can be used for the velocity determination, and often reported by NOAA as follows:

1810UTC M7.8 solar flare

1822UTC Type II sweep 1450 km/sec

NOAA uses this information to estimate the arrival time of the shockwave at earth, and the intensity of the geomagnetic storm. Of course, you can do this as well! The 1450 km/sec shockwave slows down as it travels along with the solar wind, averaging about 70% of the Type II or III value, or about 1000 km/sec. = ~625 miles/sec. With the sun about 93 million miles from earth, the travel time will be ~149,000 seconds, or about 41 hours. With the normal solar wind about 350 km/sec., an increase to 600 km/sec. generally triggers a *minor* geomagnetic storm, around 1000 km/sec. a *major* storm, and much above that, a *severe storm*. These, of course, are all rough estimates.

The shockwave also travels through the strong magnetic field lines of the *disturbance* (Fig. 11), where the electrons and particles get trapped in the closed field lines. This also produces a bursty radio emission called a **Type I storm**. These drift downward in frequency at about 2 MHz/sec. and sound like ignition noise from an idling car. A Type I storm can extend to around 10 MHz and persist for 20-30 minutes following a major flare.

Radio Emissions due to the Gas Cloud

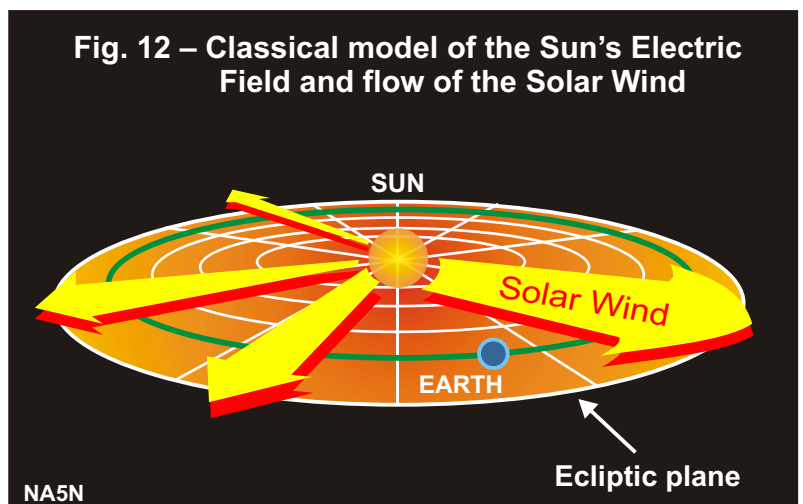
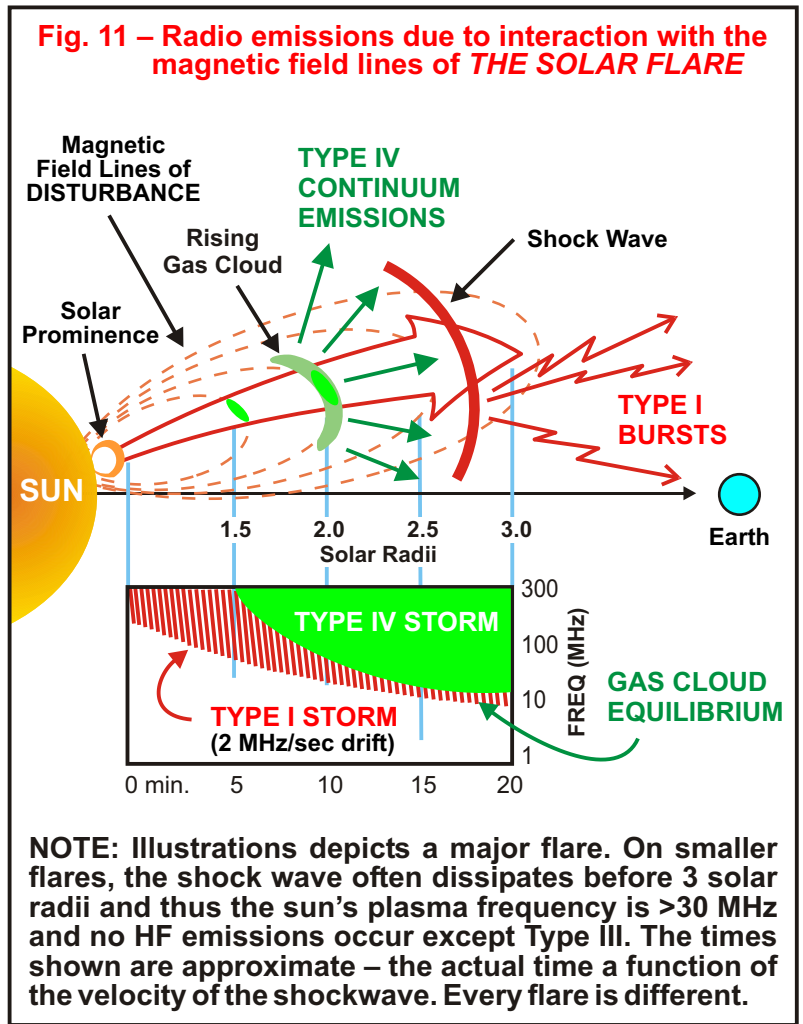
Behind the shockwave is a *gas cloud* of particles from the flare, generating wideband noise called a **Type IV Continuum Storm**. The noise begins around 1 GHz. The higher the gas cloud rises, the lower in frequency will the noise escape the sun. (That solar plasma frequency thing again). These particles rise until the pressure of the gas cloud equals the pressure of the solar atmosphere. At this point (about 15-30 minutes following the flare), the particles become stationary and generate noise down to 10-20MHz, depending upon the height of equilibrium. The Type IV storm can persist for hours following the flare and is an overall elevation of noise on HF. The exact mechanism of this noise emission from the gas cloud is not well understood.

GEOMAGNETIC STORMS

The Solar Wind

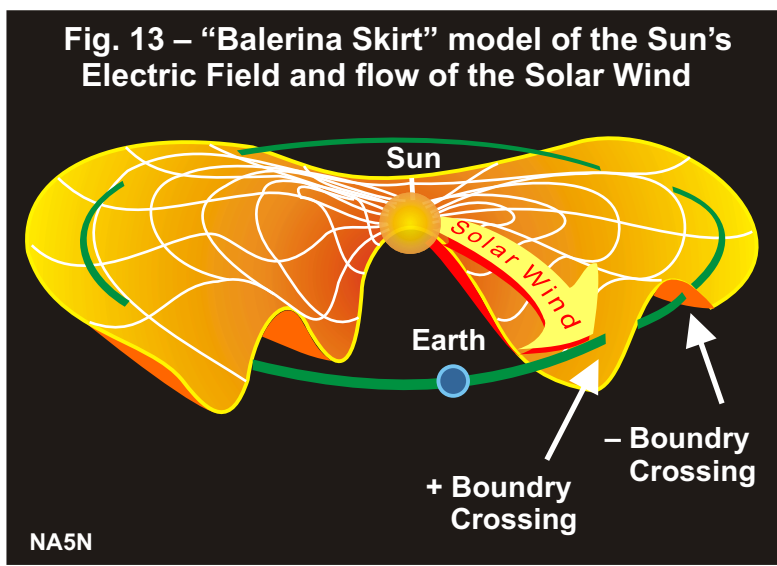
Disturbances to the *solar wind*, from a solar flare or coronal hole, can cause serious disruptions to HF by triggering a geomagnetic storm. The solar wind is the constant outflow of gasses, electrons, and particles from the sun and travel along the ecliptic plane, as shown in Fig. 12.

It was long believed that the solar wind was fairly constant, at around 350 km/sec., the escape velocity of the sun. We now know that the solar



wind is highly variable, ranging from the minimum 350 km/sec. to 2,000 km/sec. or more following a major solar flare. From years of satellite data, we now know that the sun's electric field is not flat, but instead looks more like the "balerina skirt" model shown in Fig. 13.

When the earth's orbit enters or exits the skirt, it is called a **boundry crossing**, often reported by NOAA. The sudden change in the solar wind speed, and direction of flow, can trigger a geomagnetic storm. The **-boundry crossing** causes a stronger geomagnetic storm than a positive crossing. However, they are seldom severe and last only a few hours. Fig. 13 shows why the solar wind is constantly changing, causing minor geomagnetic storms, even during very quiet solar conditions.

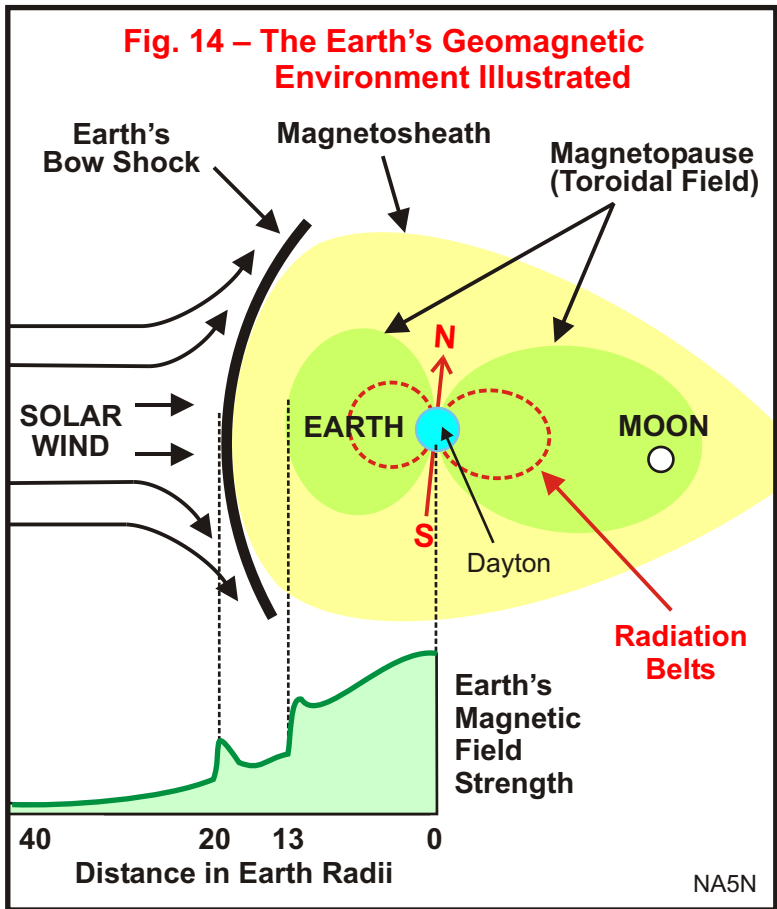


The solar wind exerts a pressure on the earth's magnetic field, which distorts the toroidal pattern as shown in Fig 14. If this pressure should suddenly change, such as with the arrival of a shockwave from a solar flare, our magnetic field suddenly changes shape in response, causing it to wiggle like a bowl of jello. This, in turn, generates strong electric currents by the dynamo effect, traveling along our magnetic field lines far above our heads. This, in turn, generates noise on the HF bands. While our geomagnetic field is wiggling, it can often produce strong, bursty noise, or "static crashes." As the geomagnetic storm begins to subside, it settles down to an elevated noise level.

QRP Propagation Hint: Often our magnetic field gets very quiet following a strong geomagnetic storm for 12–24 hours. This is an excellent time to work 40–160M due to very low noise levels.

The K and A Indices

Magnetometers on the earth measure the condition of our magnetic field. The amount of movement (or, "wiggling") is averaged and reported by NOAA as the **K-Index** every 3 hours. The K-index is a scale from 0– 9 representing quiet to severe conditions. The K-indices are averaged over 24-hours to form the **A-Index**, representing the overall planetary geomagnetic conditions for the UTC day. The A-index ranges from 0–20 for quiet conditions, up to 400 for extreme conditions. A chart showing the correlation between the K- and A-Indexes to HF noise levels is shown in Fig. 16 on the following page.



QRP Propagation Hint: Use the current **K-Index** from WWV or the internet to determine the current geomagnetic conditions. The **A-Index** is actually **yesterday's** geomagnetic condition, and does not represent present conditions.

QRP Propagation Hint: Four websites with solar information, solar flux, K and A indices and solar wind data are:
<http://www.sec.noaa.gov/today.html>
<http://www.dxlc.com/solar>
<http://www.spaceweather.com>
<http://umtof.umd.edu/pm>

Anatomy of a Solar/Geomagnetic Storm

Putting everything together, a typical strong solar and geomagnetic storm is illustrated in Fig. 15. The solar flare occurs at time 0, noted on earth by 10-30 minutes of noise bursts (Type I, II, III bursts) and elevated noise. Almost immediately, the ionizing radiation increases the MUF (whether or not it increases the solar flux). 30 minutes or more after the flare, HF noise levels return to normal, quiet conditions.

QRP Propagation Hint: This is an excellent window for QRPers, right after the flare. As soon as the solar storm ceases, HF noise levels become quiet with an elevated MUF, lasting until sundown. Night time conditions on 80-40M can be excellent. The daytime MUF the next day may be elevated as well.

Shortly after day 2, the shockwave arrives, compressing our magnetic field and triggering a major geomagnetic storm. HF noise levels immediately rise, and in severe cases, may cause an HF blackout. Electrons from the shockwave enter the earth at the poles, causing a Polar Cap Absorption (PCA) event. This causes blackout conditions on HF in the higher latitudes. The next 3-hourly K-Index will be high (6-9), sufficient to also trigger auroral activity. A major geomagnetic storm (K>6) can last 12-24 hours. When it finally subsides, our magnetic field often becomes very quiet, producing low noise levels on HF.

QRP Propagation Hint: This is the other window for QRPers, when the geomagnetic storm subsides. Night time noise levels on 40-80M can be very low.

A Few Final Thoughts

1. The **solar flux**, indicating the level of ionization, affects HF propagation **above** about 10 MHz. The solar flux does not affect 40M and below, since the MUF seldom drops below 10 MHz. This is why the lower bands are **always** open.
2. The **K-index**, indicating the geomagnetic condition, indicates HF noise primarily **below** about 10 MHz, except in severe cases. During a storm, high noise levels on 40M doesn't mean high noise on 20M.
3. 30M is the ham band caught between the 2 worlds. It can be affected by both solar flux and the K-index. On the other hand, it is more often **not** bothered by either. It is a good band throughout the solar cycle.
4. Every solar flare and the resultant storm is different. No two are alike, nor accurately predictable.
5. Never let reports of flares or geomagnetic storms scare you from getting on the air and checking it out. See #5.
6. #5 includes propagation posts on qrp-1 by NA5N!

Fig. 15 – Anatomy of a strong Solar & Geomagnetic storm

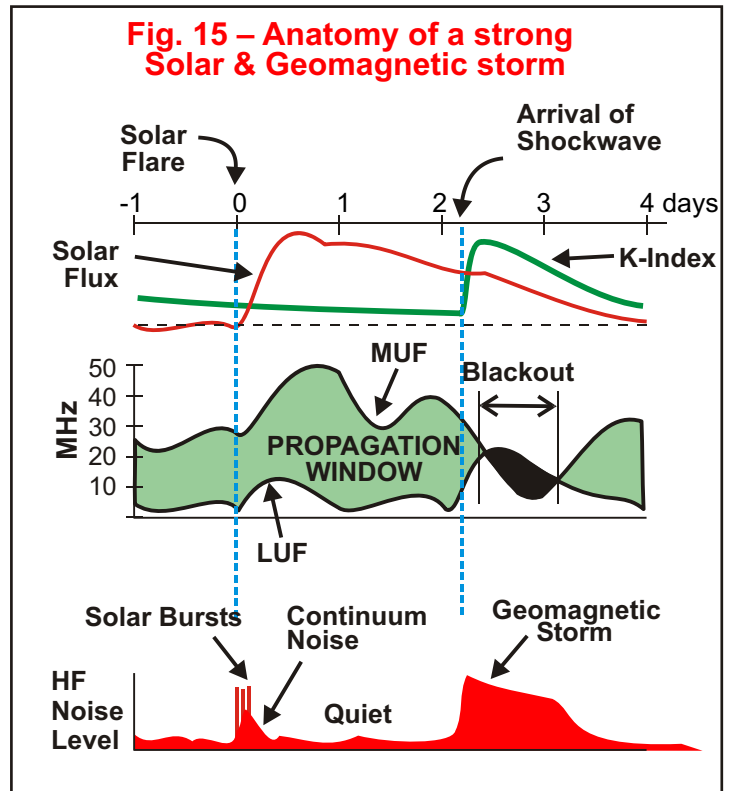


Fig. 16 – Geomagnetic Indices & Conditions

	K Index	Ap Index	Geomagnetic Conditions	HF Noise	Aurora
NORMAL	0	0-2	Very Quiet	S1-S2	None
	1	3-5	Quiet	S1-S2	None
	2	6-9	Quiet	S1-S2	Very low
	3	12-19	Unsettled	S2-S3	Very low
STORM	4	22-32	Active	S2-S3	Low
	5	39-56	MINOR storm	S4-S6	High
	6	67-94	MAJOR storm	S6-S9	Very high
	7	111-154	SEVERE storm	S9+	Very high
	8	179-236	SEVERE STORM	Blackout	Extreme
	9	300-400	EXTREME storm	Blackout	Extreme

Fig. 17 – Solar Flare Classifications

Flare Class	Type of Flare	HF Radio Effects (30M to 10M)	Geomagnetic storm (<20M)
A	Very small	None	None
B	Small	None	None
C	Moderate	† Low absorption	† Active to Minor
M	Large	† High absorption	† Minor to Major
X	Extreme	† Poss. blackout	† Major to Severe

† Conditions cited only if Earth is in the trajectory of the flare's shockwave.

I hope you have found this presentation informative and helpful. Even though now in the quiet sun, strong flares and geomagnetic storms can still occur. If you have questions, feel free to email me. I'll try my best to answer your questions.

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