SPACE WEATHER INTRODUCTORY COURSE

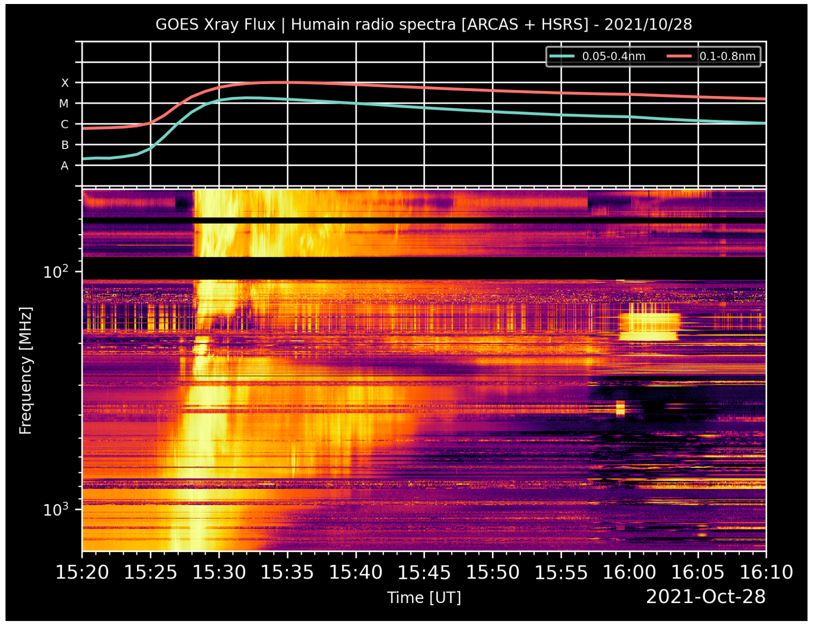
Collaboration of

Solar-Terrestrial Centre of Excellence

Koninklijke luchtmacht

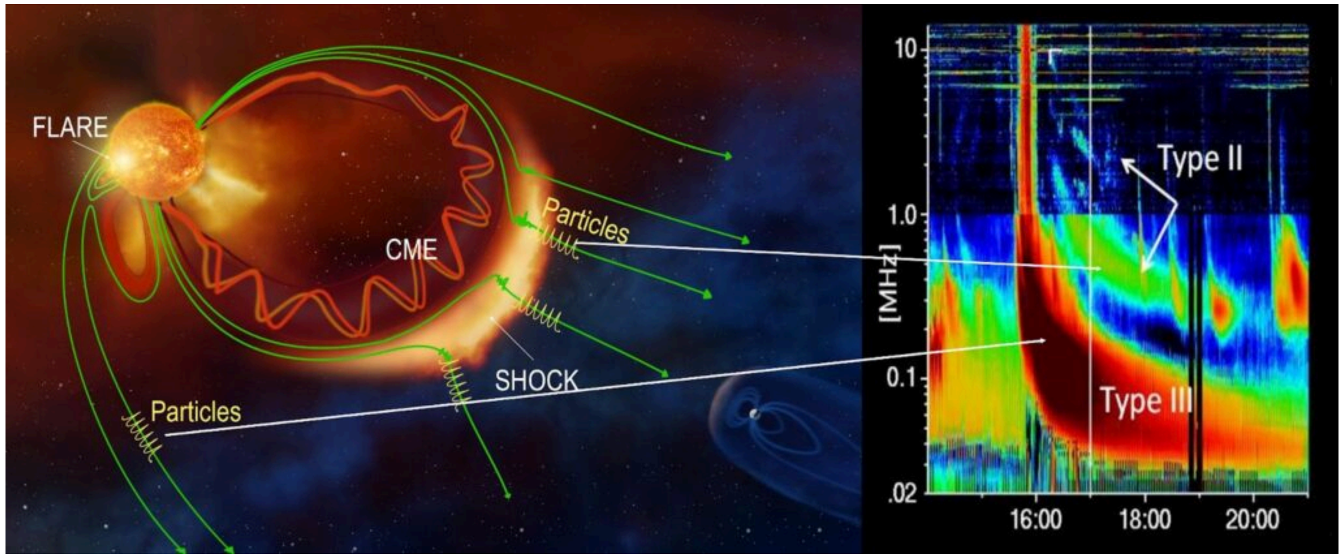
Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

RADIO BURSTS

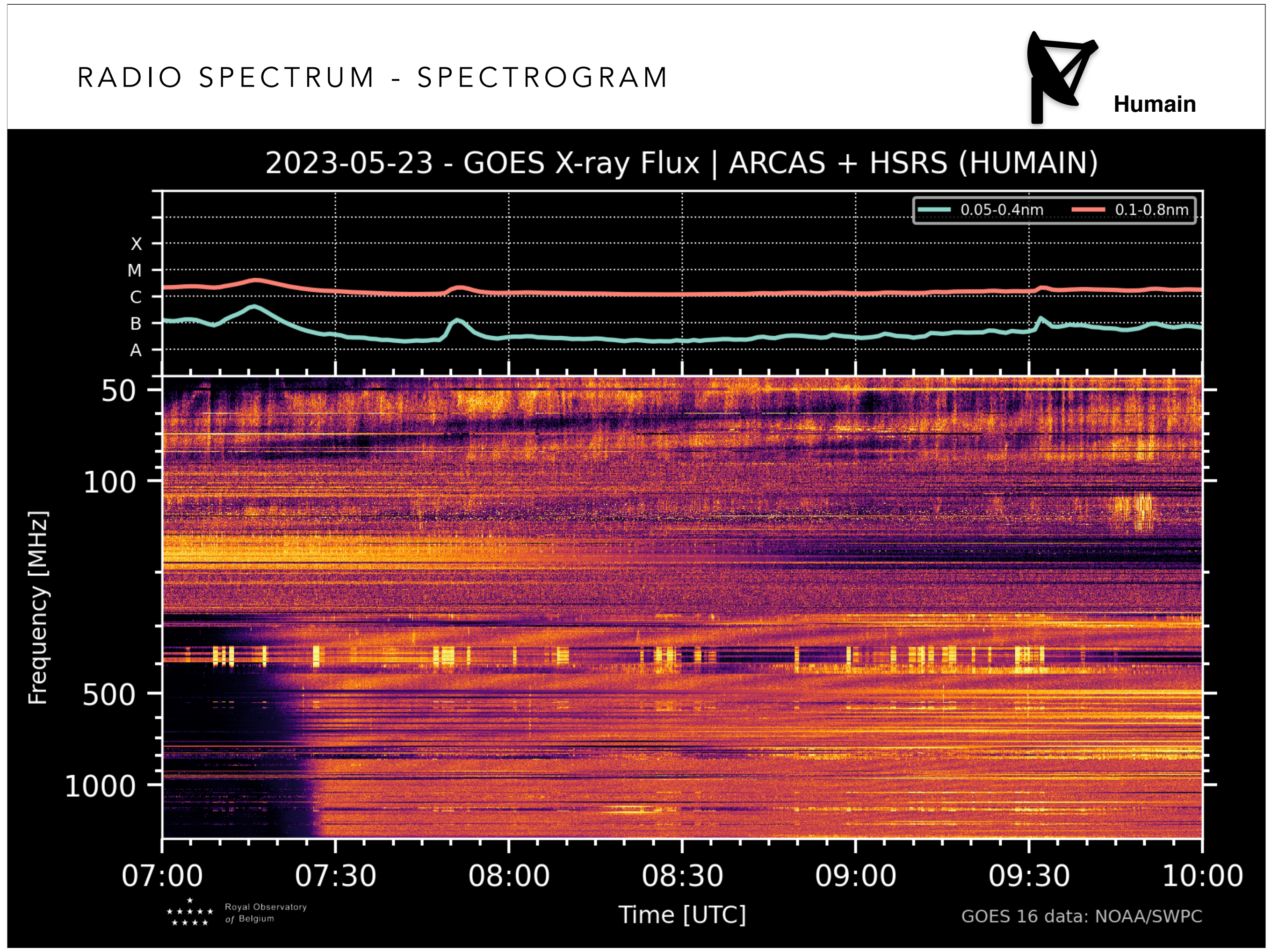


Humain

Observations in the e.m. spectrum at radio wavelengths:
•10 cm flux —> index for solar activity, similar like the sunspot index
•Solar Radio Bursts



Solar radio bursts are other electromagnetic waves emitted from accelerated electrons around the flare site, or electrons accelerated by a CME shock front which produce the direct noise on radio receivers.
Electrons start radiating because they get an energy boost from a solar event. They are a signature of occurrence of a CME or flare. As such, a SRB are not a consequence of magnetic reconnection.



We can measure the **solar e.m. radio output and put it into a spectrogram**.
At low frequencies, **5 types** of radio wave bursts are seen, **each with a unique signature in frequency and time.**

A type II burst is caused by a shock that triggers the local plasma to emit radio waves. While **most of the interplanetary shocks are CME-driven, coronal shock waves can be attributed to solar flares**, CMEs, or some combination of these two phenomena. Since the acceleration phase of the CME and the flare impulsive phase are usually closely synchronized, it is **hard to distinguish between the flare energy-release effects and the CME expansion**. Due to this problem the origin of the coronal shocks, i.e. metric type II bursts, still remains unresolved.

Type II

type II burst, slowly drifting, often with fundamental/2nd harmonic structure, due to plasma emission
cause is a shock wave, propagating at 500-2000 km/s outward into the corona into interplanetary space (also seen down to kilometric wavelengths).

Type III

- type III burst, rapidly drifting, often with fundamental/2nd harmonic structure, due to plasma emission. The fundamental is highly o-mode polarized, and the 2nd harmonic is weakly (15%) x-mode polarized.
    - cause is a stream, or **beam, of electrons moving at speed ~ c/3, propagating from low corona into interplanetary space** (also seen down to kilometric wavelengths).
- type III storm -- a long lasting (up to a day or more) series of type III bursts, RS (reverse slope) bursts, reverse-drift pairs, and continuum.

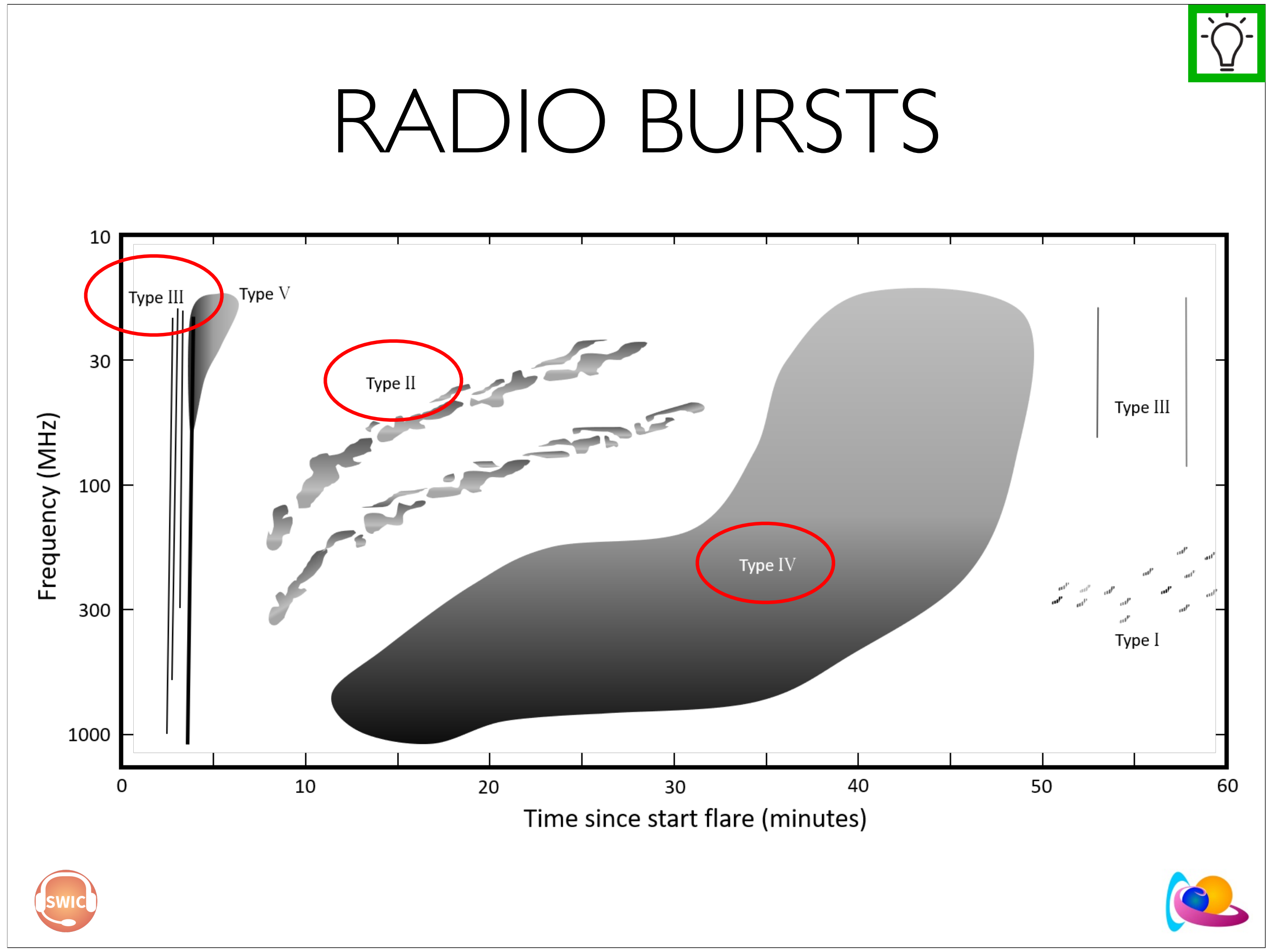
Type IV

- stationary type IV -- broadband continuum emission, sometimes highly polarized, due to either plasma emission (o-mode polarized) or gyrosynchrotron emission (x-mode polarized).
    - cause is a plasmoid or high, filled loops of non-thermal particles
- moving type IV -- a similar cause, but entrained in a CME or expanding arch.

Type V

- type V burst, continuum emission following a type III burst, x-mode polarized (opposite sense to the associated type III)
    - cause is **slower type III-like electrons** in widely diverging magnetic fields, with both forward and counterstreaming langmuir waves, perhaps generated by previous passage of type III electrons.

linked with a solar event, like a flare, CME, languir waves



SRBs are produced by electrons energised by solar eruptive events, like flares, coronal mass ejections. Their signature in a spectrogram gives information about the fate of these electrons. Type II, III and IV are important for space weather.

Source of Figure: https://www.sws.bom.gov.au/World_Data_Centre/1/9/4
This diagram illustrates all of the major burst types in a typical configuration following a large flare. It should be noted that it is not common for all of these features to be observed after a flare.

Mind the orientation of the vertical axis! Other figures may have a reversed direction. As the frequency is proportional to the square root of the density, and the density decreases with increasing distance from the Sun, a **decreasing frequency means locations higher up in the solar atmosphere.**

The **ionospheric cut-off frequency** is around 15MHz (due to too low frequency and so **reflected by ionosphere**). In order to observe radio disturbances below this frequency, one has to use **satellites** (above the earth atmosphere) such as STEREO/SWAVES or WIND. Radio bursts at low frequencies (< 15 MHz) are of particular interest because they are associated with energetic CMEs that travel far into the interplanetary (IP) medium and affect Earth's space environment if Earth-directed. Low frequency radio emission needs to be observed from space because of the ionospheric cutoff.
Example: https://stereo-ssc.nascom.nasa.gov/browse/2017/01/16/insitu.shtml

Solar Radio Bursts and Space Weather, S.M. White
https://www.nrao.edu/astrores/gbsrbs/Pubs/AJP_07.pdf
Solar radio bursts at frequencies below a few hundred MHz were classified into 5 types in the 1960s (Wild et al., 1963).

Coronal Mass Ejections and solar radio emissions, N. Gopalswamy
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.708.626&rep=rep1&type=pdf
The three most relevant to space weather radio burst types are type II, III, and IV. Three types of low-frequency non-thermal radio bursts are associated with coronal mass ejections (CMEs): Type III bursts due to accelerated electrons propagating along open magnetic field lines, type II bursts due to electrons accelerated in shocks, and type IV bursts due to electrons trapped in post-eruption arcades behind CMEs.

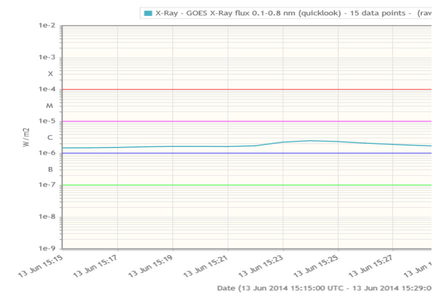
[Radio burst type II, III, and IV are also the only ones that ever get mentioned in the Ursigrams.]

See also: https://www.stce.be/educational/classification

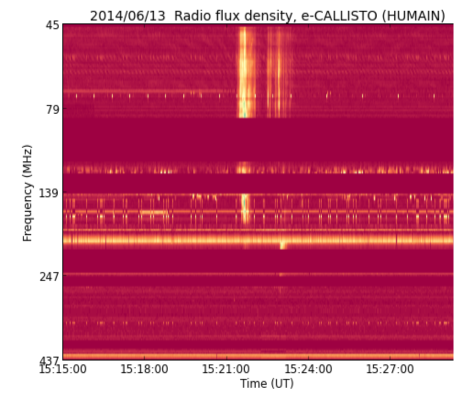
RADIO BURSTS

Type III

- Source:
  - accelerated electrons propagating along open magnetic field lines
- During impulsive phase of flares
- Duration
  - Seconds (isolated) to minutes (groups)
- Frequency
  - 10 kHz-1GHz



GOES



Humain

Rather than examine each event Type in numerical order, this discussion treats each event Type in the order in which they are most likely to be encountered (i.e. from most to least common).

Image courtesy:
GOES-curve: STAFF viewer, http://www.staff.oma.be
Radio plot: ROB/Humain Radio Observatory, http://www.sidc.be/humain/

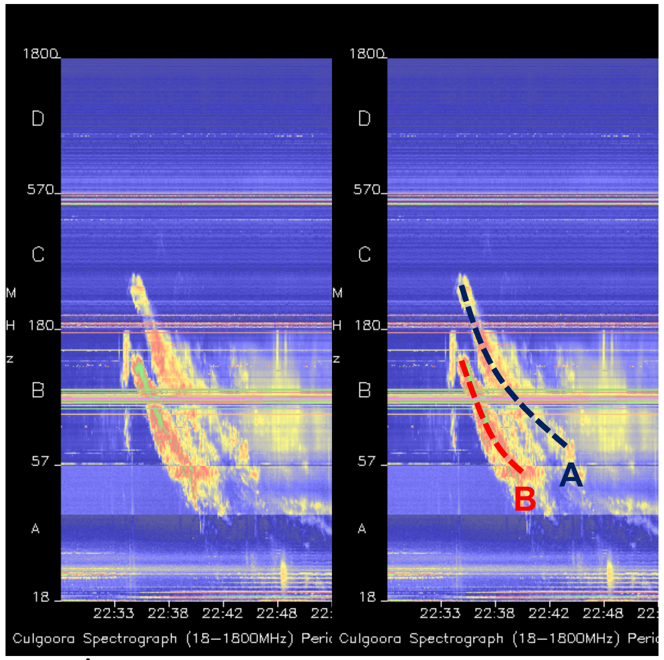
13 June 2014

3940.	1521	1524	1527	G15	5	XRA	1-8A	C2.4	5.2E-04	2087
3940 +	1521	1522	1523	SAG	G	RBR	245	290		2087
3940 +	1521	////	1523	SAG	C	RSP	025-180	III/2		2087
3940 +	1522	1522	1525	HOL	3	FLA	S19E38	SF		2087

Solar Radio Bursts and Space Weather, S.M. White
https://www.nrao.edu/astrores/gbsrbs/Pubs/AJP_07.pdf
Type III bursts are brief radio bursts that drift very rapidly in frequency versus time (Fig. 1). For example, it can drift from 50 to 20 MHz in about 3 seconds, or 10 MHz s−1. Type IIIs are commonly seen in the impulsive phase of solar flares, and the connection they imply between the acceleration region in solar flares and open field lines that reach the solar wind makes them important for understanding field line connectivity in flares and the access of flare-accelerated particles to the Earth.

RADIO BURSTS

Type II
- Source:
  - electrons accelerated in shocks
  - Indicates CME
  - Shock speed can be derived from fundamental band (B)
- Start at peak in soft X-ray flux of flare
- Duration
  3-30 minutes
- Frequency
  20-150 MHz



Culgoora

Culgoora spectrograph at 01 Nov 2003 – http://www.sws.bom.gov.au/Solar/2/2/1 (Type II/2, 1079 km/s)

Solar Radio Bursts and Space Weather, S.M. White
https://www.nrao.edu/astrores/gbsrbs/Pubs/AJP_07.pdf
Type II bursts typically occur at around the time of the soft X-ray peak in a solar flare and are identified by a slow drift to lower frequencies with time in dynamic spectra, the frequent presence of both fundamental and **second-harmonic** bands (with a frequency ratio of 2), and splitting of each of these bands into two traces. The frequency drift rate is typically two orders of magnitude slower than that of the ("fast-drift") Type III bursts, so the two burst types are readily distinguished.

The harmonic is almost always stronger than the fundamental.

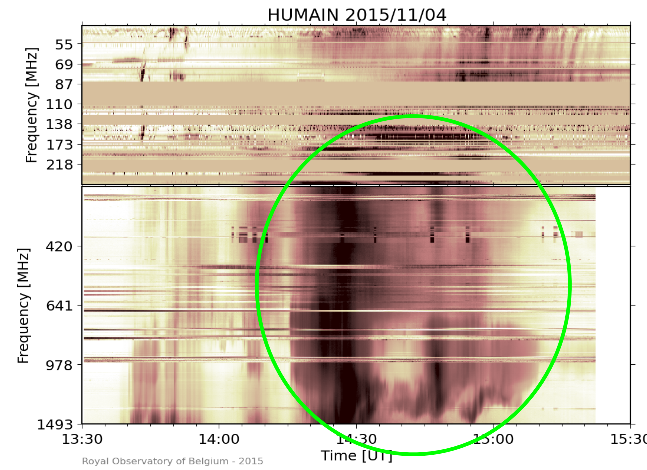
The fundamental band is the one provoked by the shock of the CME and is the one that reaches the lowest frequencies first (track « B » in the image). It is the fundamental track that is used to calculate the (true) speed of the shock as it moves through the corona and away from the Sun (density decrease => frequency decrease).

Roberts (1959): Solar Radio Bursts of Spectral Type II : http://adsabs.harvard.edu/abs/1959AuJPh..12..327R
Gopalswamy: Coronal Mass Ejections and solar radio emissions : http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.708.626&rep=rep1&type=pdf

RADIO BURSTS

Type IV

- Source
  - Electrons trapped in post-eruption arcades behind CMEs
  - Related to very energetic CMEs
    (average speed: 1200 km/s)
- During decay phase of solar flares
  Connection with SEPs
- Duration
  Hours (to days)
- Frequency
  - 20 to >1000 MHz
  - Lowest: 8 +/-5 MHz



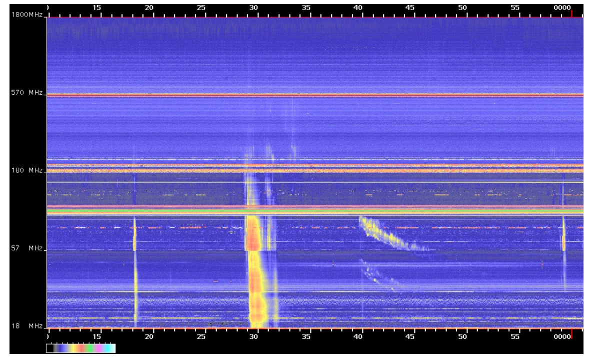
Humain

Gopalswamy: Coronal Mass Ejections and solar radio emissions
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.708.626&rep=rep1&type=pdf
The type IV bursts are associated with very energetic CMEs (average speed 1200 km/s), confirming the earlier finding by Robinson [1986] for the **continuum** events at metric wavelengths. The radio emission should originate from a heliocentric distance 3.5 to 4.5 Rs, depending on whether the radio emission occurs at the fundamental or harmonic of the plasma frequency. When the type IV burst attains the lowest frequency, the IP type II burst occurs at frequencies well below 1 MHz, which means the shock is much farther away. This suggests that the energetic electrons responsible for the type IV burst might come from the continued reconnection occurring beneath the CME.
[Comment by Dr Christophe Marqué (ROB): The height of type IV reported by Gopalswamy concerns the low frequency ones. The one for example observed in Humain (04 Nov 2015) is really taking place in the post flare loops close to the flare site.]

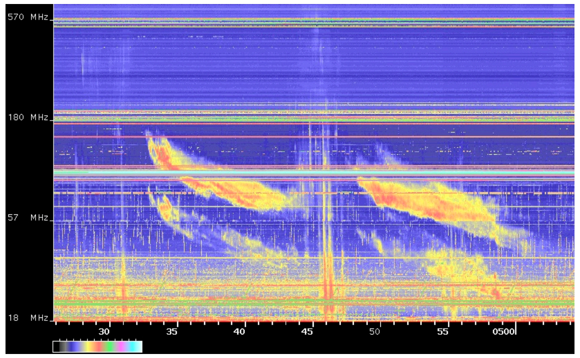
Solar Radio Bursts and Space Weather, S.M. White
https://www.nrao.edu/astrores/gbsrbs/Pubs/AJP_07.pdf
Type IV bursts are broadband quasi-continuum features associated with the decay phase of solar flares. They are attributed to electrons trapped in closed field lines in the post-flare arcades produced by flares; their presence implies ongoing acceleration somewhere in these arcades, possibly at the tops of the loops in a “helmet-streamer” configuration. Type IV bursts have long been of interest in Space Weather studies because they have a high degree of association with solar energetic particle events.

Example: 04 Nov 2015: http://www.stce.be/news/326/welcome.html
2340B1327 U1339 A1348 SVI 2 FLA N09W04 2B ERU 2443
2340 + 1331 1352 1413 G15 5 XRA 1-8A M3.7 5.9E-02 2443
2340 + 1336 1341 1438 SVI G RBR 4995 740 2443
2340 + 1337 1341 1442 SVI G RBR 2695 340 2443
2340 + 1337 1341 1429 SVI G RBR 8800 560 2443
2340 + 1338 1341 1414 SVI G RBR 15400 210 2443
2340 + 1343 //// 1358 SAG C RSP 048-180 II/2 955 2443
2340 + 1351 //// 1531 SVI C RSP 025-171 IV/1 2443
2340 + 1404 1426 1502 SAG G RBR 410 1400 2443
2340 + 1405 1433 1507 SAG G RBR 245 1400 2443
2340 + 1406 1427 1456 SAG G RBR 1415 5800 2443
2340 + 1406 1427 1458 SAG G RBR 610 1000 2443

RADIO BURSTS

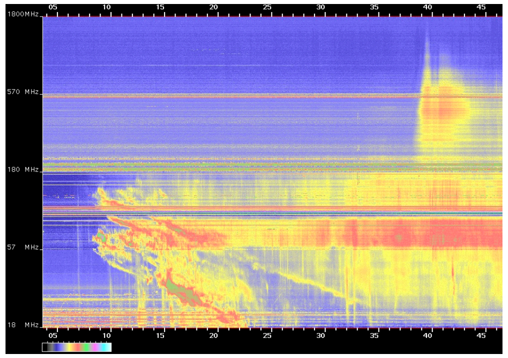


Type II preceded by Type III bursts



Two Type II bursts with background noise

Culgoora

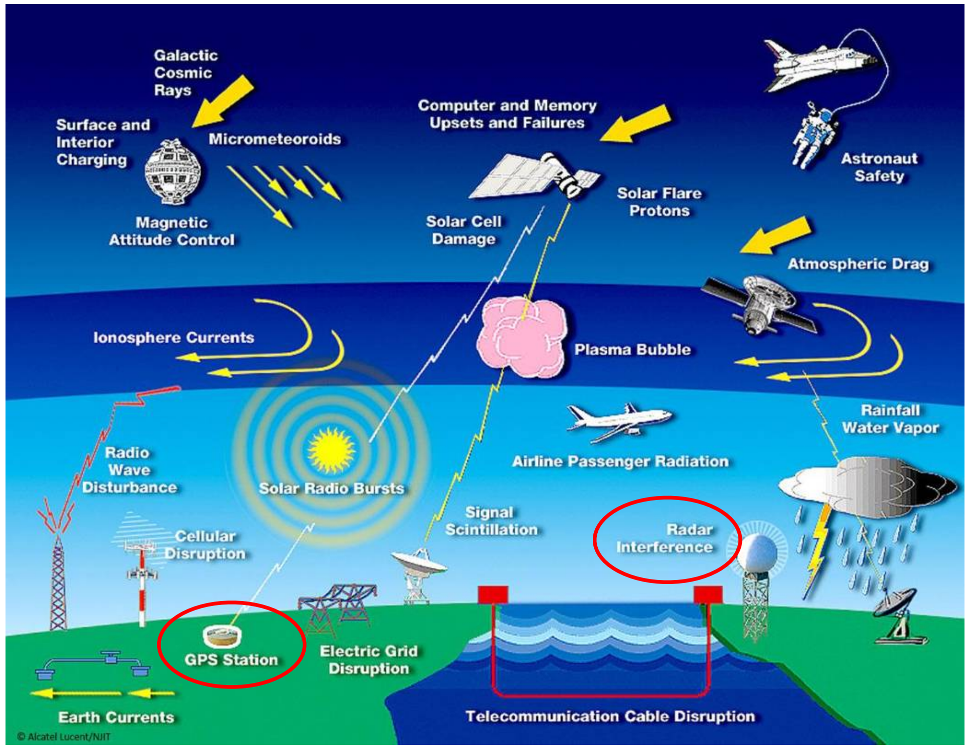


Long duration Type II
with Type IV continuum

Images taken from: https://www.sws.bom.gov.au/World_Data_Centre/1/9/5

Often, for strong bursts, multiple signatures can be seen at the same time.

IMPACT?



Can a Solar Radio Burst impact the ionosphere?

SRB can impact radar systems and GNSS but it a complete other way compared to flares.
Flares, i.e. ionising radiation impacting the ionosphere.
The radio waves from a SRB behave as a wave used by the GNSS and radar technology.

Noise increase - the ionosphere is not impacted but the signal itself. The noise of the Sun is too loud, the GNNS receiver can't hear the satellite signal clear enough. Or the radar interprets the radio waves coming from the Sun as being a plane.

Image Source: https://www.nasa.gov/mission_pages/sunearth/news/gallery/agu11-spaceweather.html

GPS station Signal/noise - signal is from the satellite.
GPS receivers are designed to be sensible to the signal above them, not at the horizon. When there is a strong radio burst - in the typical GPS frequencies - the noise increases.
Radar interference
Radars are monitoring the planes near the horizon - descending and ascending planes. Radar may see ghost planes due to extra radio-signals coming from the Sun.
HF Com: f you have a strong radio burst in HF, your MUF might be full of solar noise and in practice not usable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:Issued: 2023 Mar 06 1246 UTC
:Product: documentation at http://www.sidc.be/products/meu
#--------------------------------------------------------------------#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC     #
# (RWC Belgium)                                                      #
#--------------------------------------------------------------------#
SIDC URSIGRAM 30306
SIDC SOLAR BULLETIN 06 Mar 2023, 1245UT
SIDC FORECAST (valid from 1230UT, 06 Mar 2023 until 08 Mar 2023)
SOLAR FLARES  : M-class flares expected (probability >=50%)
GEOMAGNETISM  : Active conditions expected (A>=20 or K=4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 06 Mar 2023  10CM FLUX: 181 / AP: 013
PREDICTIONS FOR 07 Mar 2023  10CM FLUX: 178 / AP: 011
PREDICTIONS FOR 08 Mar 2023  10CM FLUX: 170 / AP: 006
COMMENT: Solar flaring activity was high in the past 24 hours with a five M-class flares detected and several C-class flares. NOAA Active Region (AR) 3242 (magnetic type Beta, Catania group 5) produced two M1 flares yesterday at 16:41 UT and 17:01 UT, NOAA AR 3243 (magnetic type Beta), produced two M5 flares yesterday at 21:36 UT and today at 02:28 UT, while NOAA AR 3234 (magnetic type beta-gamma-delta) an M1 flare at 09:12 UT today. NOAA AR 3238 (magnetic type Beta, Catania group 1), 3242, and 3243 have a fair chance of producing more M-class flares, while there is still a small chance for an isolated X-flare in the next 24 hours.

Several Coronal Mass Ejections and flows were observed in the currently available SOHO/LASCO coronagraph imagery and automatically detected by the Cactus tool over the past 24 hours. However, no clear Earth-directed CME were identified.

The greater than 10 MeV proton flux was at nominal levels over the past 24 hours and is expected to remain so for the next 24 hours. The greater than 2 MeV electron flux was above the 1000 pfu alert threshold and is expected to fluctuate around this threshold during the next 24 hours. The 24h electron fluence was at nominal levels and is expected to remain so. The 24-hour electron fluence was at moderate levels and is expected to remind at moderate levels over the next 24 hours.

The Solar Wind (SW) conditions remain under the influence of the fast solar wind streams associated to the equatorial coronal hole of negative polarity that reached the central meridian on March 02. The SW speed ranged between 500 km/s and 630 km/s. The total interplanetary magnetic field (Btot) had values between 3 nT and 8 nT, and its North-South component (Bz) fluctuated between -7 nT and 6 nT. The solar wind conditions near Earth are expected to remain at the same level for the next 24 hours.

Geomagnetic conditions were moderate to active both globally and locally (NOAA Kp and K Dourbes 2-4) over the last 24 hours. The are expected to remain at the same level both globally and locally in the next 24 hours.

TODAY'S ESTIMATED ISN  : 192, BASED ON 12 STATIONS.

SOLAR INDICES FOR 05 Mar 2023
WOLF NUMBER CATANIA    : ///
10CM SOLAR FLUX        : 180
AK CHAMBON LA FORET    : 037
AK WINGST              : ///
ESTIMATED AP           : 027
ESTIMATED ISN          : 155, BASED ON 12 STATIONS.

                    NOTICEABLE EVENTS SUMMARY
                    DAY BEGIN MAX  END  LOC    XRAY OP  10CM Catania/NOAA RADIO_BURST_TYPES
                    05  1624  1641 1653 N10W12 M1.0 SF       01/3238
                    05  1653  1701 1711 ////// M1.0          05/3242
                    05  2129  2136 2141 ////// M5.0     91   ///3243
                    06  0208  0228 0235 N19W65 M5.8 2N  480  06/3243      IV/1III/1VI/2
                    06  0857  0912 0937 ////// M1.3          ///////      III/1
                    END
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Radio bursts

Importance: weak - normal - strong

The type of radio burst is followed by a number indicating its importance.
The importance is a scale from 1 to 3 indicating how well the radio burst was observed: 1 is weak, 2 is normal, 3 is strong.