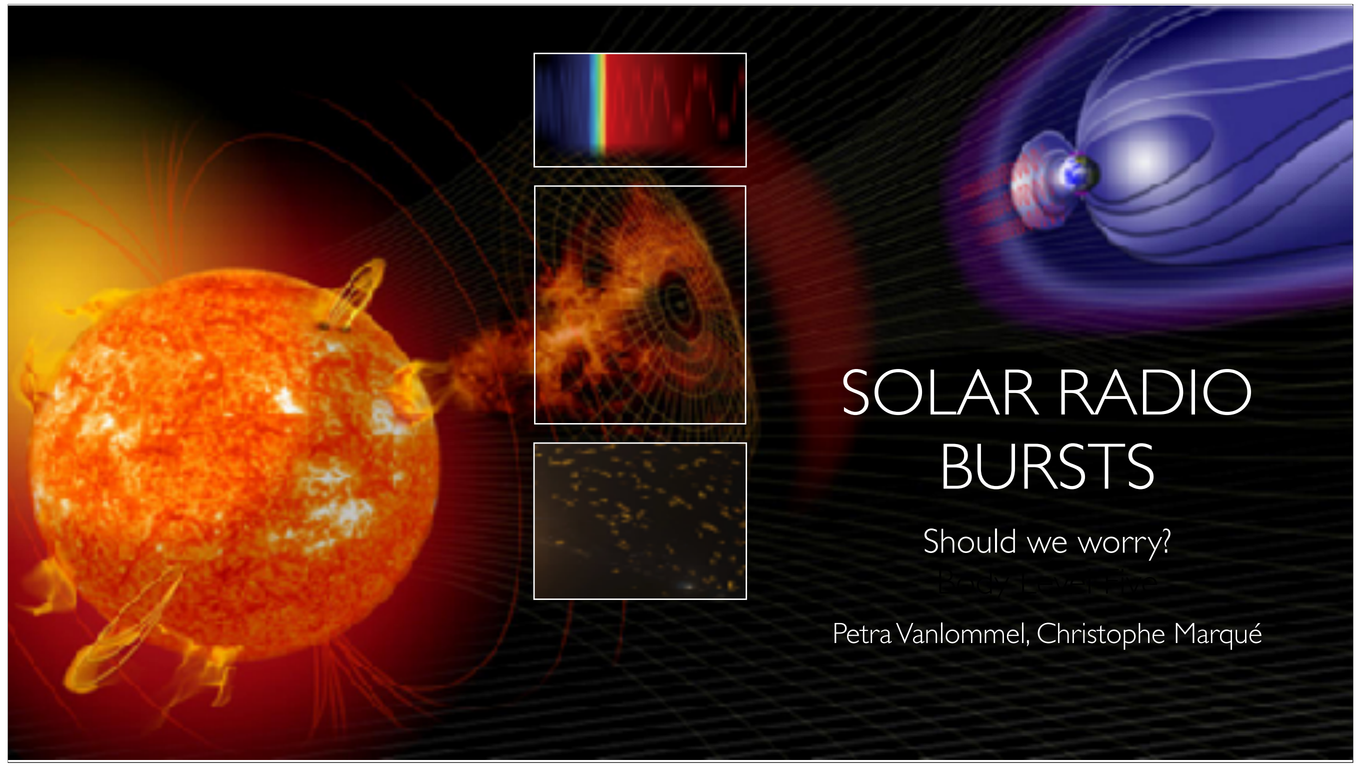
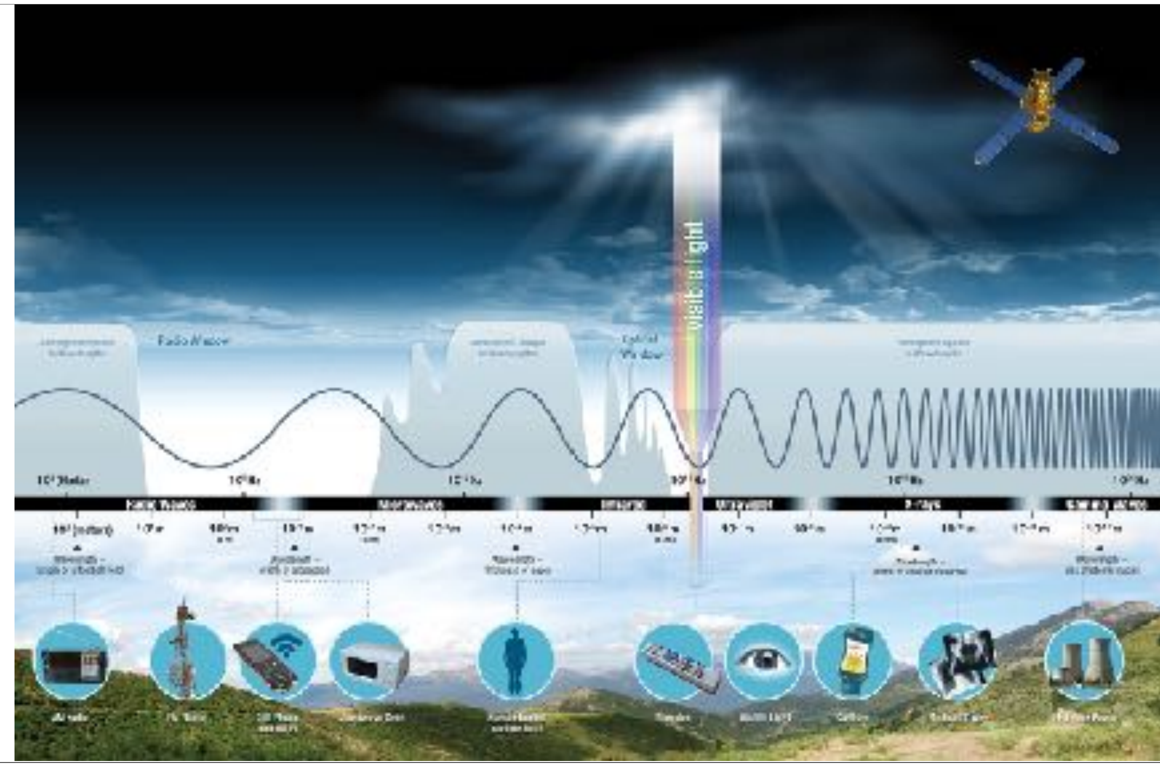
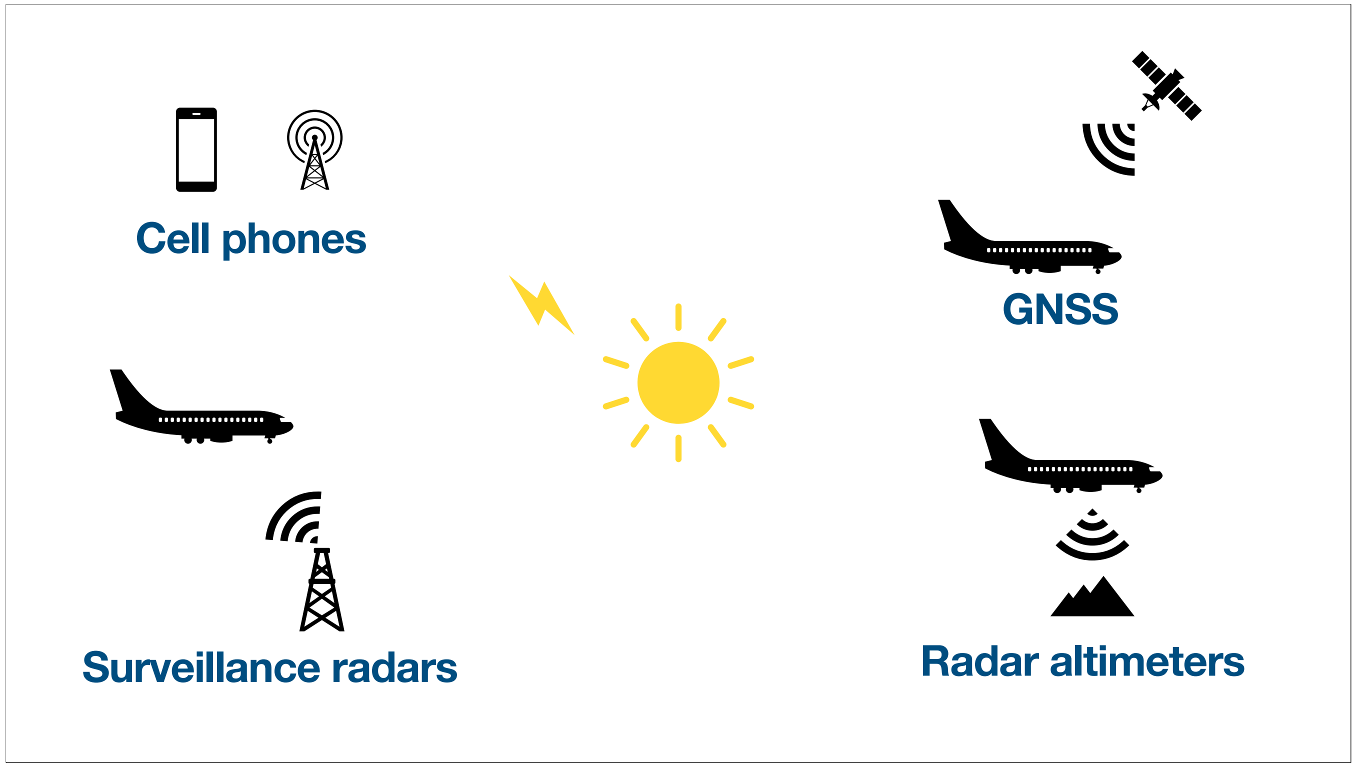

SOLAR RADIO BURSTS
Should we worry?
Petra Vanlommel, Christophe Marqué

Solar Radio Burst

Solar radio bursts are produced by non thermal electrons accelerated during eruptive events of all magnitudes
For frequencies (f) below ~ 1 GHz, the dominant emission is called plasma emission, where energetic electrons trigger local plasma oscillations which are then converted into E. M. radiations



Radio window = between 30 MHz and 100 GHz
The left of the radio window is ELF —- HF com - Reflection by the ionosphere
The right of the radio window, e.m. waves are being absorbed by the atmosphere.



All these systems operate with radio waves within the radio window
Receivers - picking up radio signals

Problem is often noise

Noise

- Thermal Noise: Any object with a temperature above absolute zero radiates electromagnetic energy. This includes the antenna's own loss resistance and the sky and ground, which the antenna picks up from its environment.
  - Ground Noise: The ground has a temperature of about 300K, varying throughout the day. Noise from the ground is particularly significant for antennas pointing toward the horizon.
  - Sky Noise: This includes cosmic background radiation and noise from the Earth's atmosphere, which varies depending on where the antenna is pointing.
- Atmospheric Noise: Natural electromagnetic noise generated by electrical processes in the atmosphere, most notably lightning.
- Human-Made Noise (RFI): Radio frequency interference from human-made sources such as power lines, other electrical devices, and communication systems.
- Shot Noise: This type of noise occurs in plasmas and is related to the discrete nature of charge carriers.

Noise in radio systems

"A time-varying electromagnetic phenomenon having components in the radio-frequency range, apparently not conveying information and which may be superimposed on, or combined with, a wanted signal."

ITU REC 573

Minimum noise level in systems

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Quiet Sun

Thermal emission from the hot corona.
The radio Sun is the strongest radio source in the sky.

A estimated man-made noise on Earth;
B, galactic noise;
C, galactic noise (toward the galactic center with infinitely narrow beamwidth);
D, quiet Sun (0.5-deg beamwidth directed at the Sun);
E, Earth atmospheric radiation, 0-to 90-deg elevation angles; and
F, blackbody (2.7-K) radiation [6].

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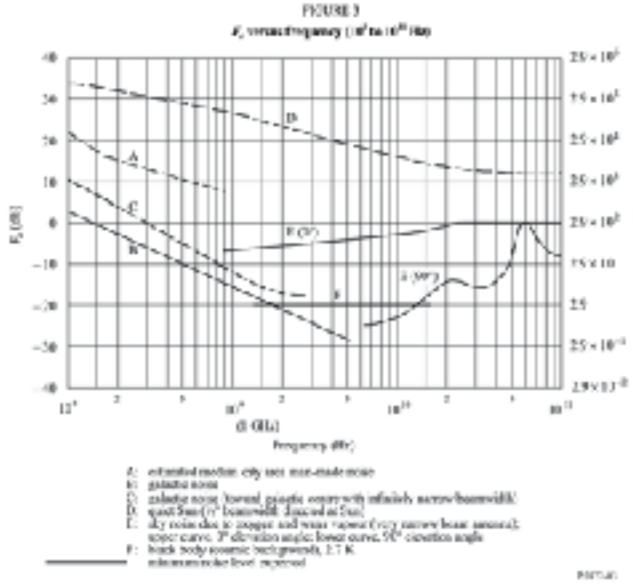

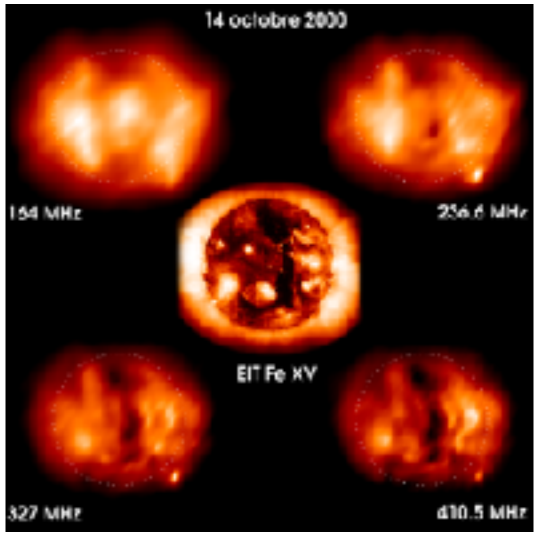

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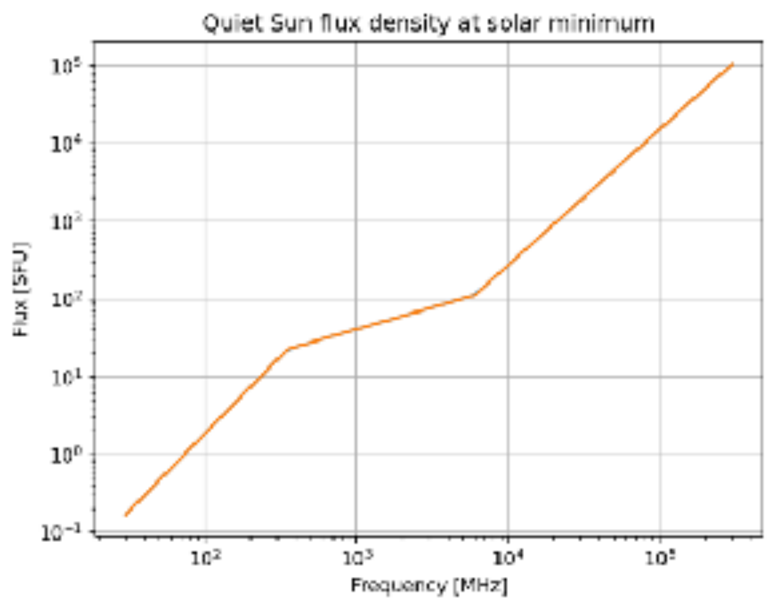
Quiet Sun flux at solar cycle minimum



One value of the 10 cm flux value per day —> excellent indicator for solar activity like the sunspot number

Solar irradiance per frequency

10.7 cm flux —> 2800 MHz
sfu => 10−22 W·m−2·Hz−1

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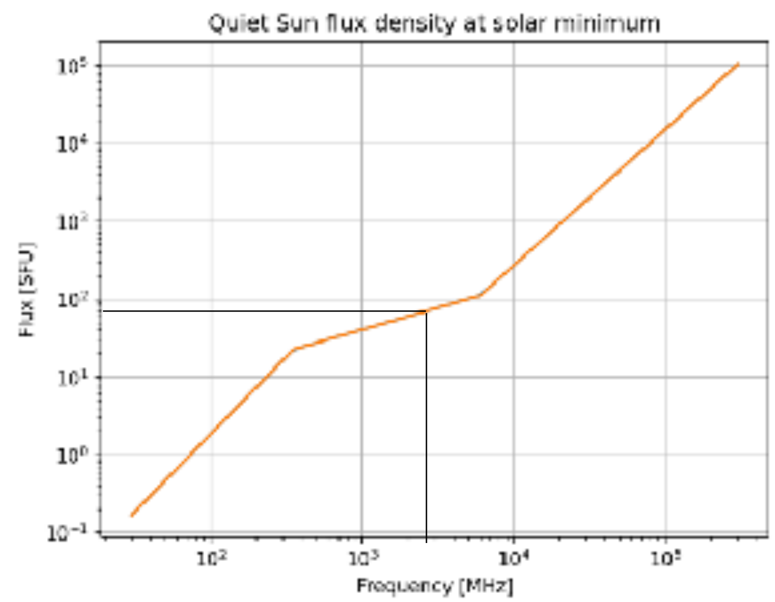

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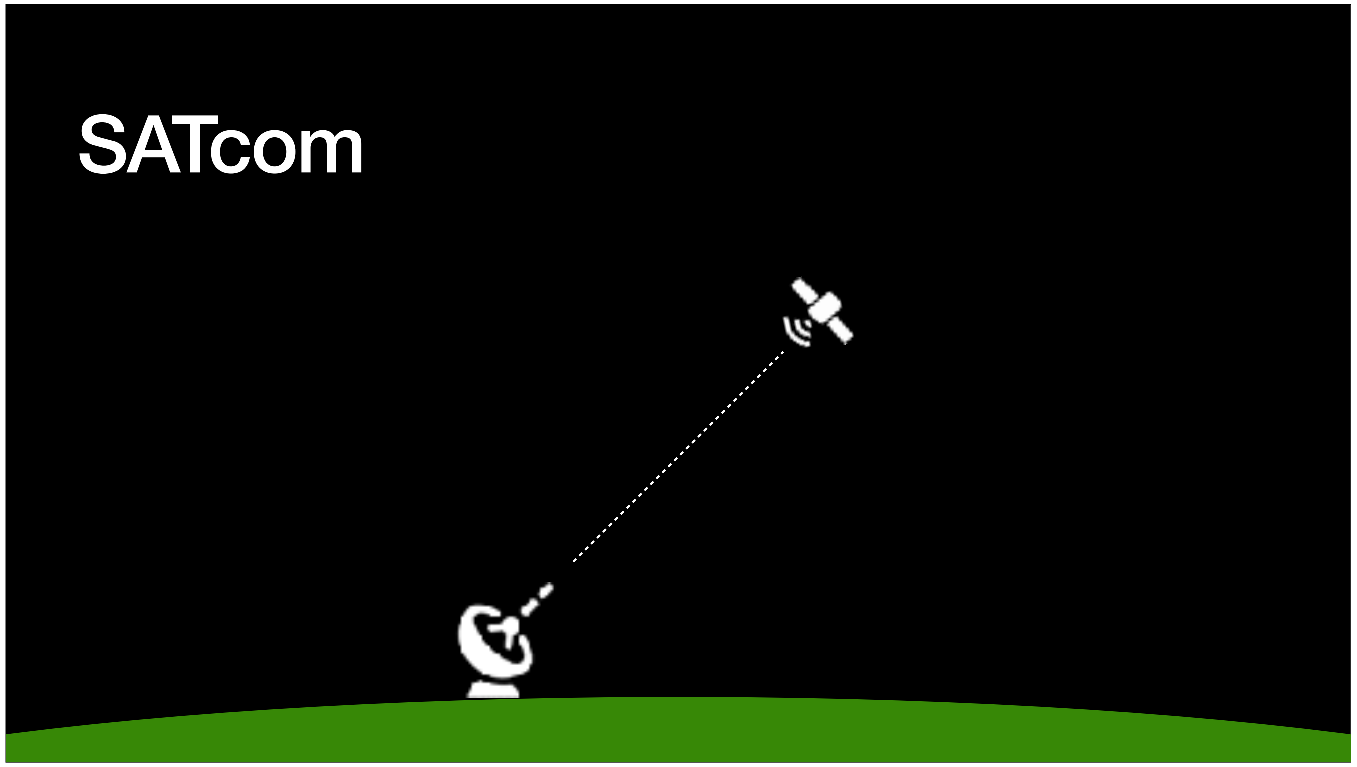
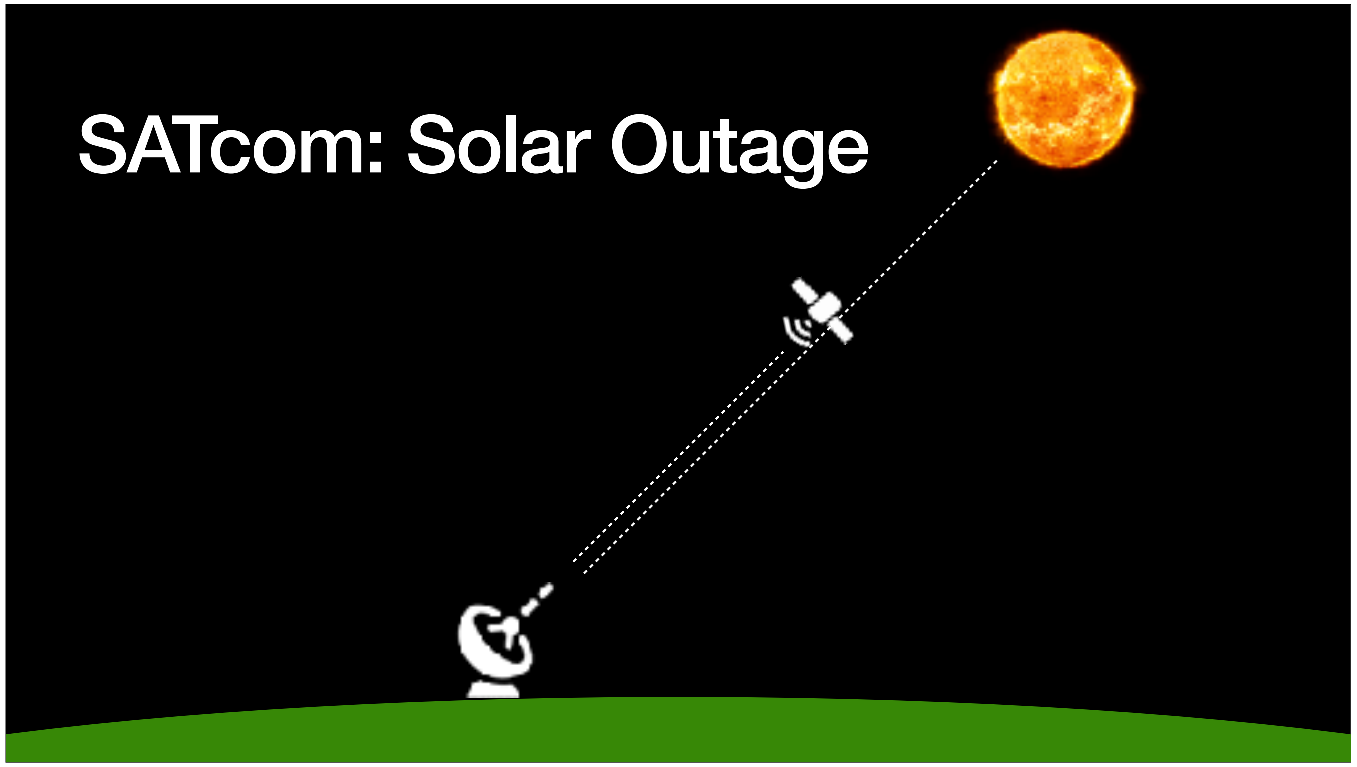
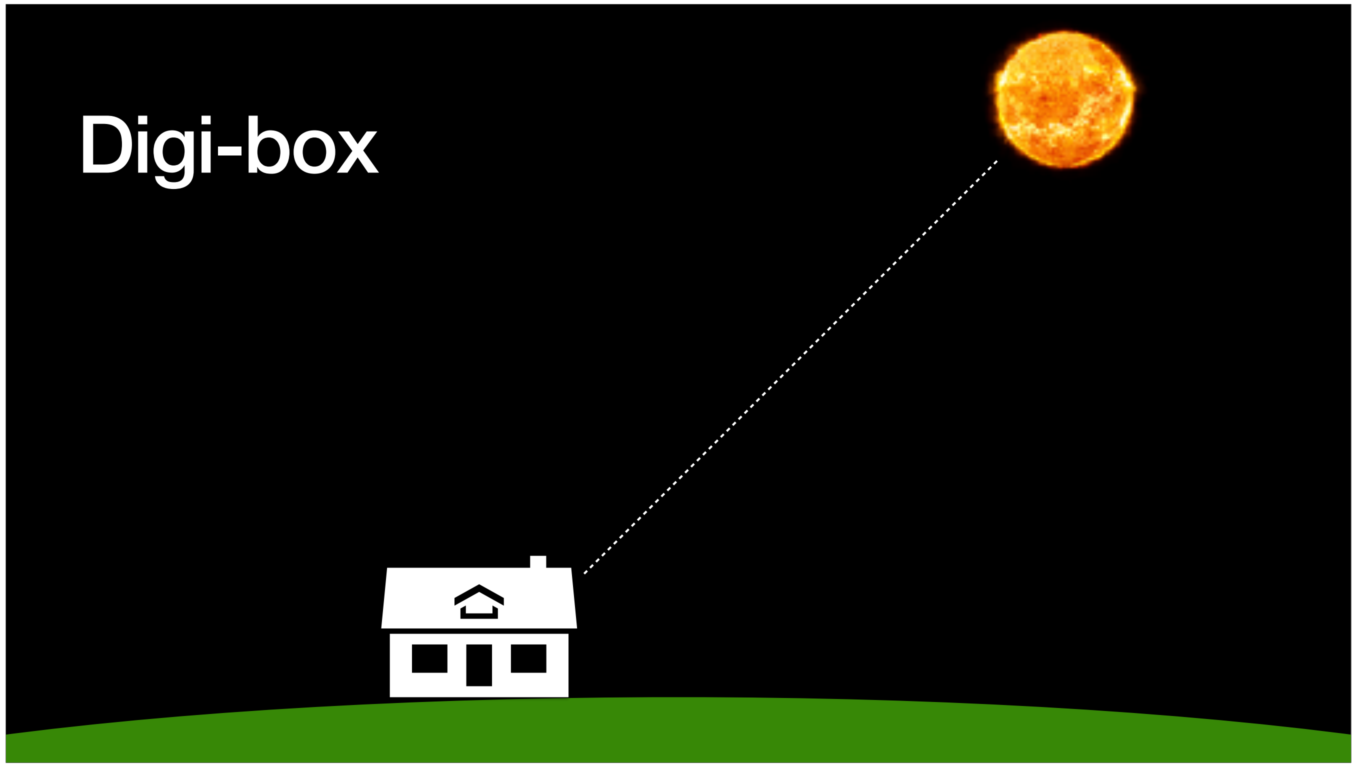


At high frequencies, SATCOM Ka band 20.7 GHz
Geostationary satellites
Applications

- Telecommunications: Used for television broadcasting, satellite internet, and other communication services that require a constant link to a specific area.
- Weather Monitoring: NOAA's GOES satellites, for example, provide continuous images of weather patterns, helping with forecasts for hurricanes, thunderstorms, and other severe weather events.
- Broadcasting: Television signals can be broadcast to large geographical areas without the need for multiple ground transmitters.



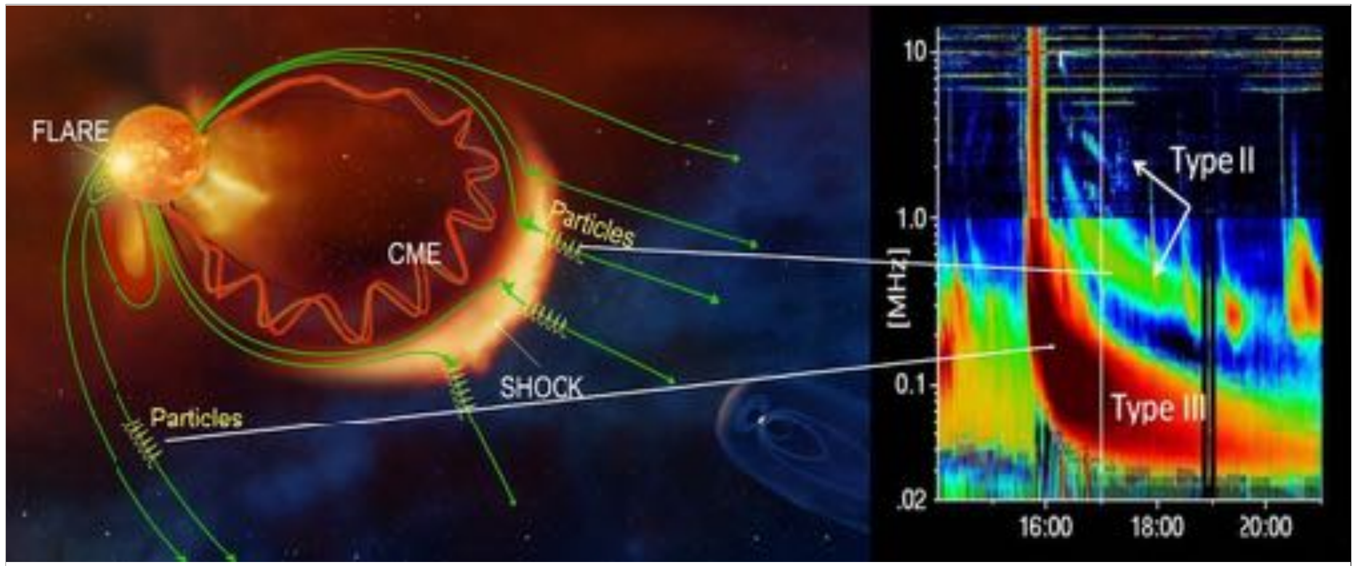
Occur when the Sun is in the Field of View
For geostationary satellites occur around equinoxes, for 10s of minutes/day for about 2 weeks
The sun radiates with enough power to overrule the satellite signal with noise.



Remote control to control the digi-box

Solar radio bursts

Non-thermal emission



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.

At which frequency?

The electron density and the plasma frequency are related

Oscillation of free electrons in the plasma depends on the electron density

Plasma frequency

$$f_p \approx 8.9\sqrt{N_e}$$

Solar radio bursts are produced by non thermal electrons accelerated during eruptive events of all magnitudes.

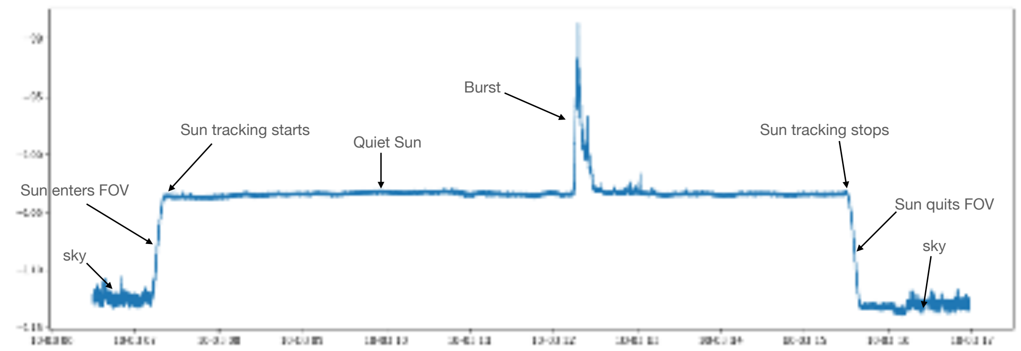
For frequencies (f) below ~ 1 GHz, the dominant emission is called plasma emission, where energetic electrons trigger local plasma oscillations which are then converted into E. M. radiations

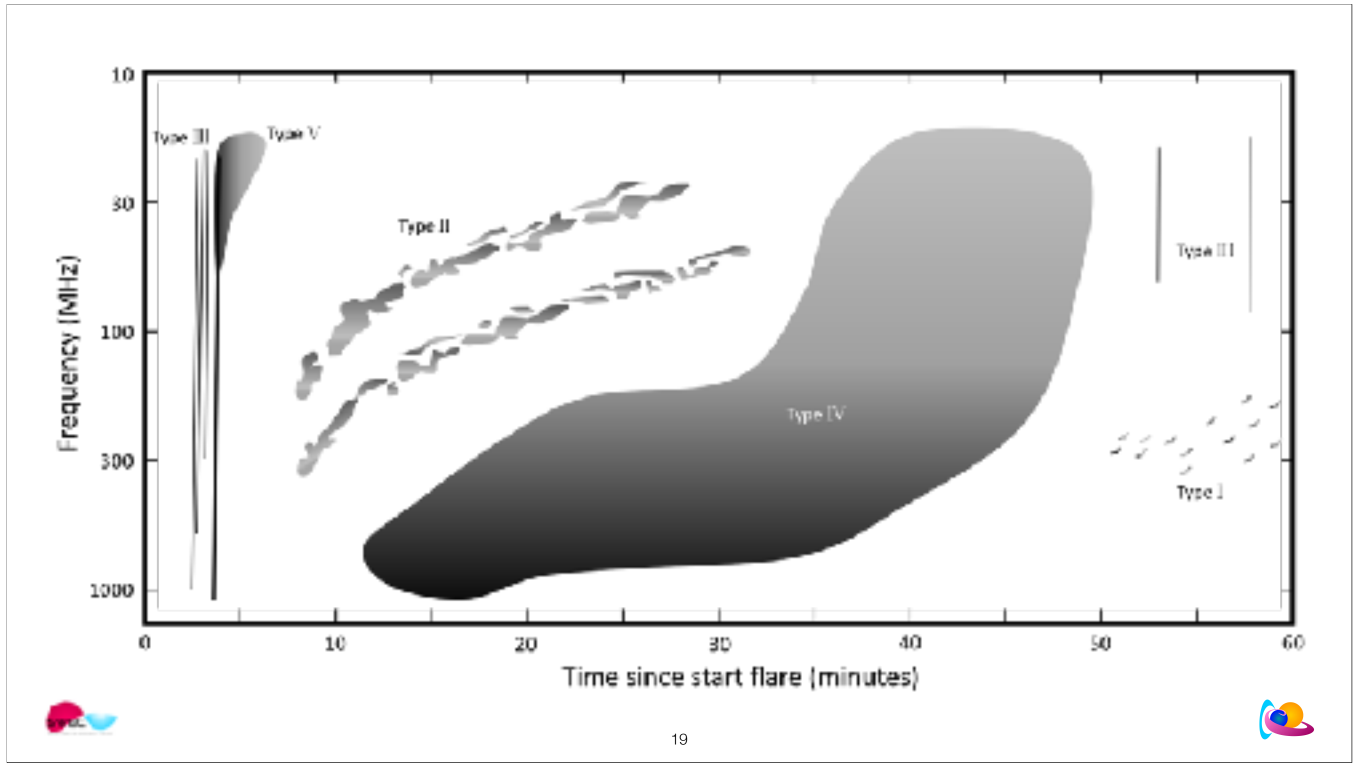
Spectral signatures (type I, type II, type III …)

The plasma frequency is the resonant frequency of the electrons in an ionized medium.
There is a direct relation between the electron density and the plasma frequency, which can be approximated as f ≈ 8.9 Ne^1/2.

Example in L band

Solar observations from Belgium





SRB are produced by energetic electrons accelerated by solar eruptive events, like flares, coronal mass ejections. Their radial signature - how it looks like in a spectrogram - tells something about the fate of these electrons.

Tells us something about the fate of the electron: trapped or pushed forward

Detected by measuring e.m. waves in the radio wavelength
Type II, III and IV are important for space weather.

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
Gopalswamy: 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.]

****

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.

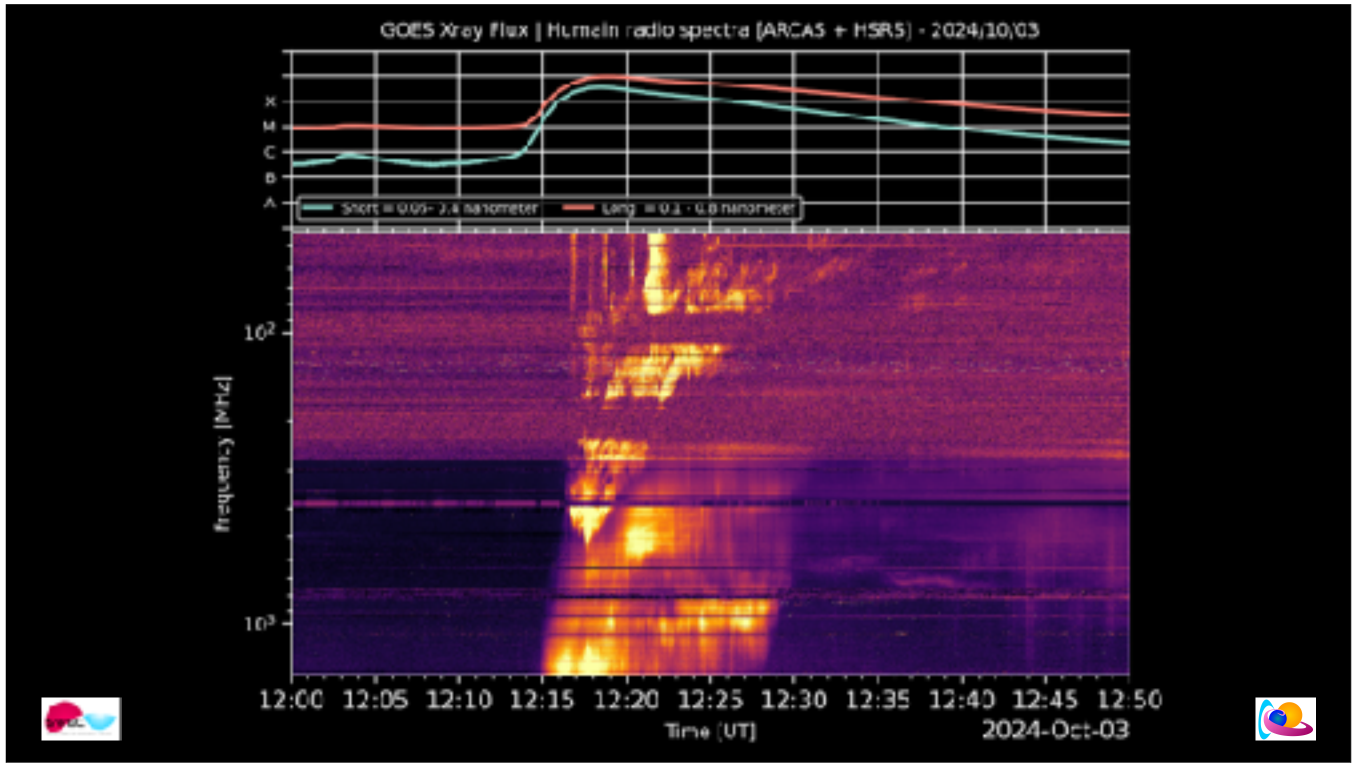
Type V

- 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

Christophe Marqué
Solar radio researcher

Antonio - Ingineer- expert



Note: 10.7cm —> 2800 MHz: not in this spectrum

Measured on the ground

f ~ N^1/2

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

Can a Solar Radio Burst impact the ionosphere?

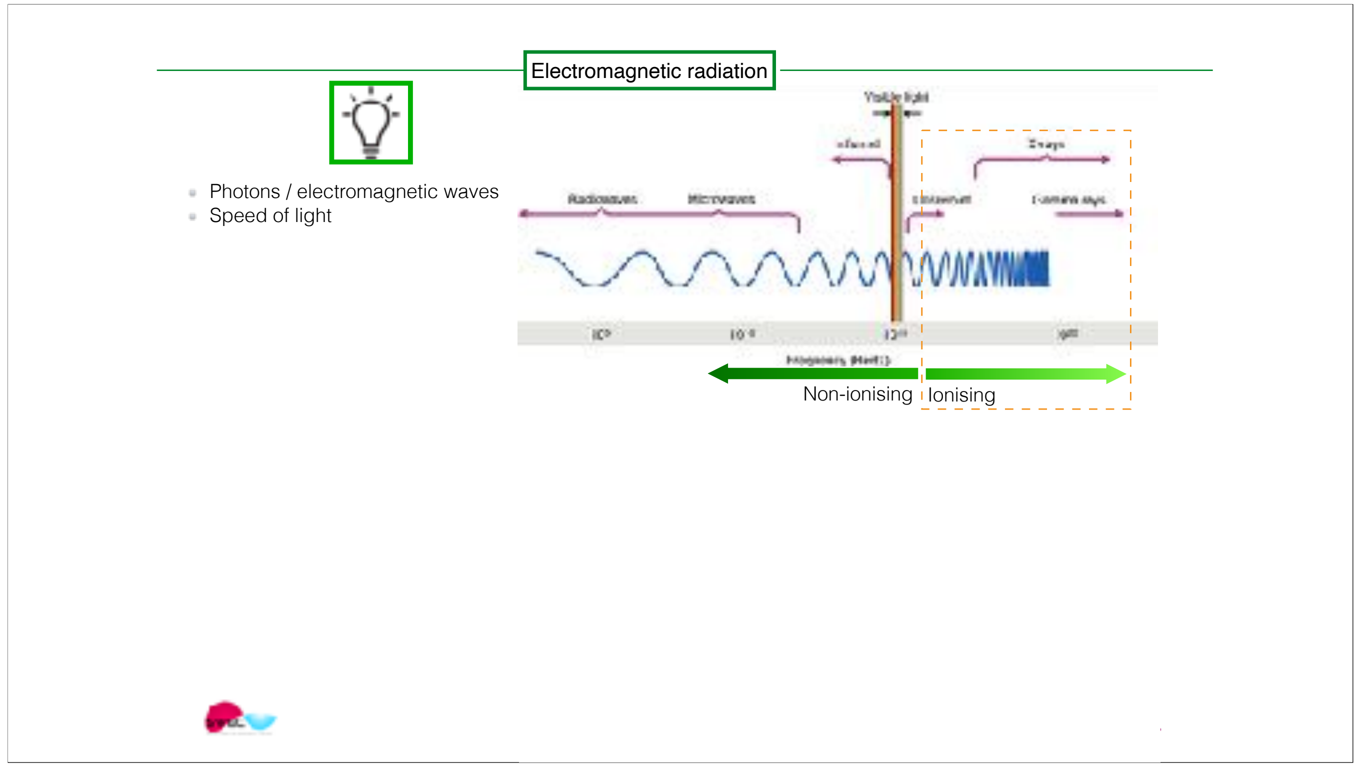
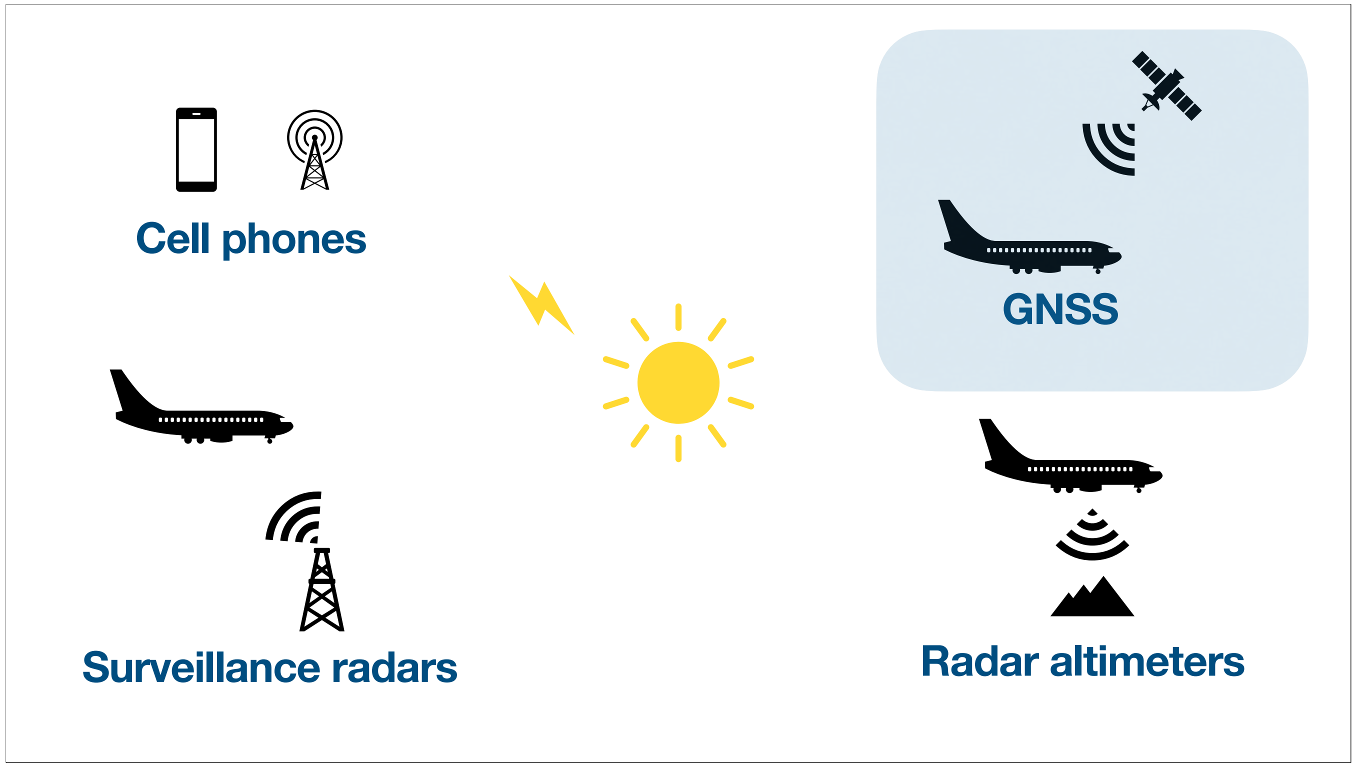


Photo-ionisation — green

Ionizing radiation is a type of energy released by atoms that travels in the form of electromagnetic waves (gamma or X-rays) or particles (neutrons, beta or alpha). The spontaneous disintegration of atoms is called radioactivity, and the excess energy emitted is a form of ionizing radiation.

Ionizing radiation (or ionising radiation), including nuclear radiation, consists of subatomic particles or electromagnetic waves that have sufficient energy to ionize atoms or molecules by detaching electrons from them.[1] Some particles can travel up to 99% of the speed of light, and the electromagnetic waves are on the high-energy portion of the electromagnetic spectrum.

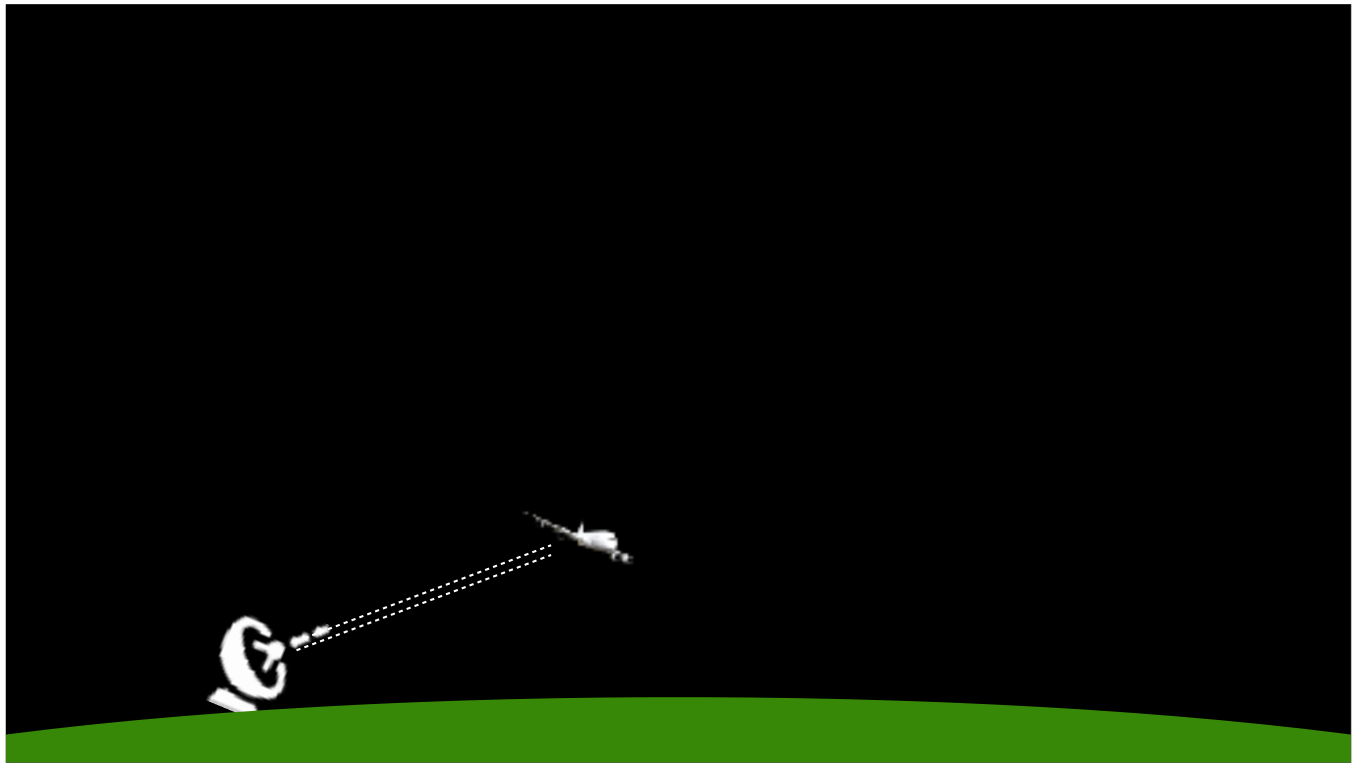
Gamma rays, X-rays, and the higher energy ultraviolet part of the electromagnetic spectrum are ionizing radiation, whereas the lower energy ultraviolet, visible light, nearly all types of laser light, infrared, microwaves, and radio waves are non-ionizing radiation. The boundary between ionizing and non-ionizing radiation in the ultraviolet area cannot be sharply defined, as different molecules and atoms ionize at different energies. The energy of ionizing radiation starts between 10 electronvolts (eV) and 33 eV.


Cell phones
GNSS
Surveillance radars
Radar altimeters

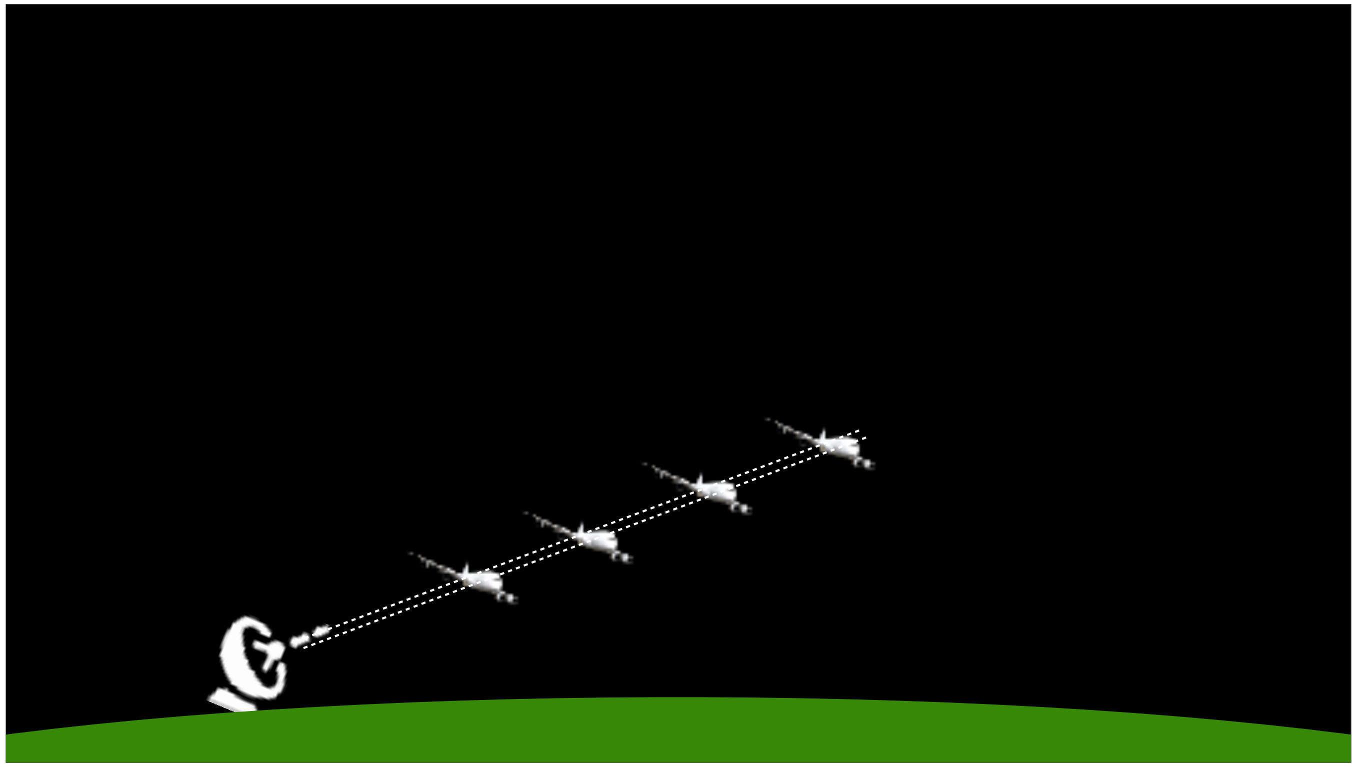
November 4 2015

A media storm

- ATC radars in Sweden suffered severe disturbances between 14:20 UT and 16:00 UT
- Incoming flights were deviated, no departures allowed
- Geomagnetic storm was initially considered as the source of disturbances (media)



Radar interference
Radars are monitoring the planes near the horizon - descending and ascending planes.
Radar ‘ziet’ vliegtuigen door de reflectie van radio-signaal. Radio-signalen van de zon kunnen geïnterpreteerd worden als ‘spook’-vliegtuigen: vliegtuigen die je ziet op het radar-scherm maar er in werkelijkheid niet zijn.



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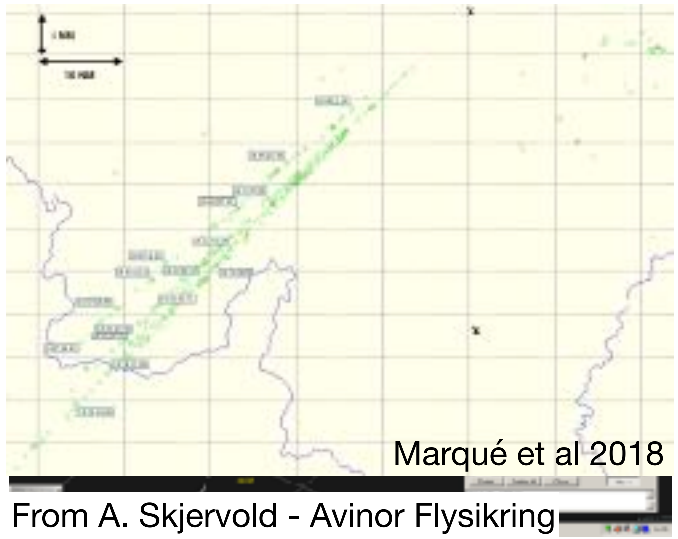
A European wide disruption

- Sweden: ATC radars suffered severe disturbances 14:20 UTC - 16:00 UTC
- Sweden: Partial closure of air space for an hour
- Minor disturbances in Norway, Belgium



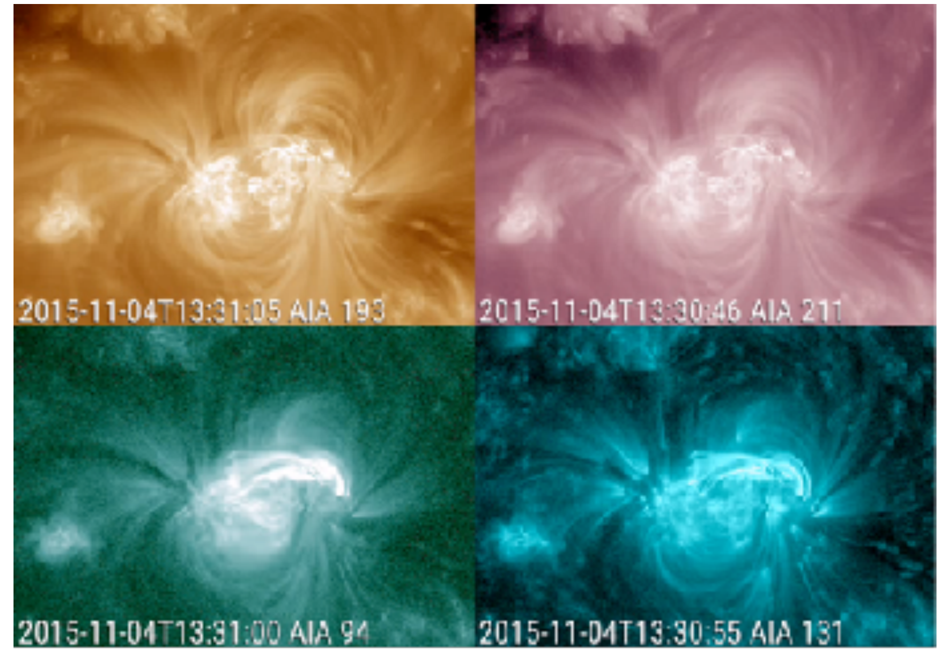
Marqué et al 2018

From A. Skjervold - Avinor Flysikring

Belgium: sunset on Nov 4
15:42 UTC – 16:42 CET (UTC +1)

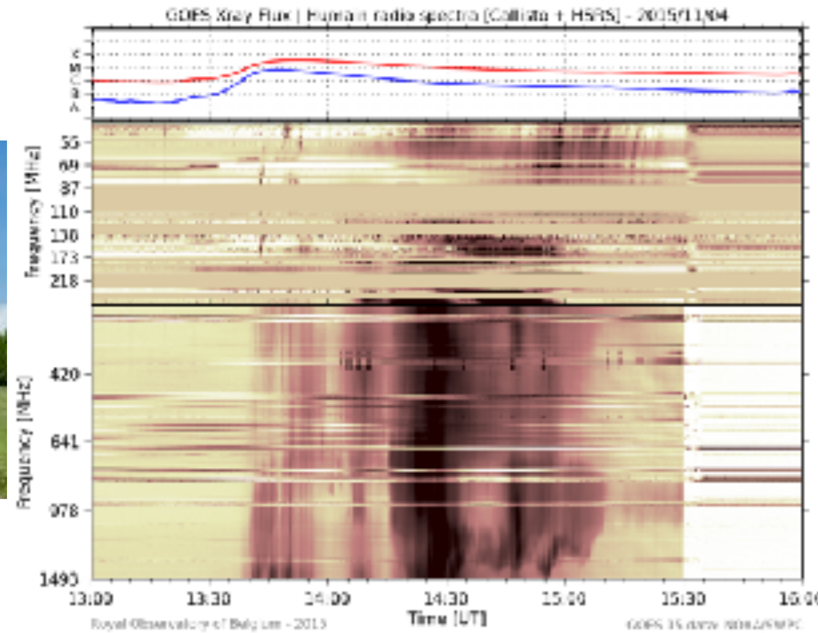
Solar event

M3.7 flare
peaking @1352 UT



Belgium: sunset on Nov 4
15:42 UTC – 16:42 CET (UTC +1)
Flare peak 1352 UTC – 1452 CET

In Humain



https://www.sidc.be/humain

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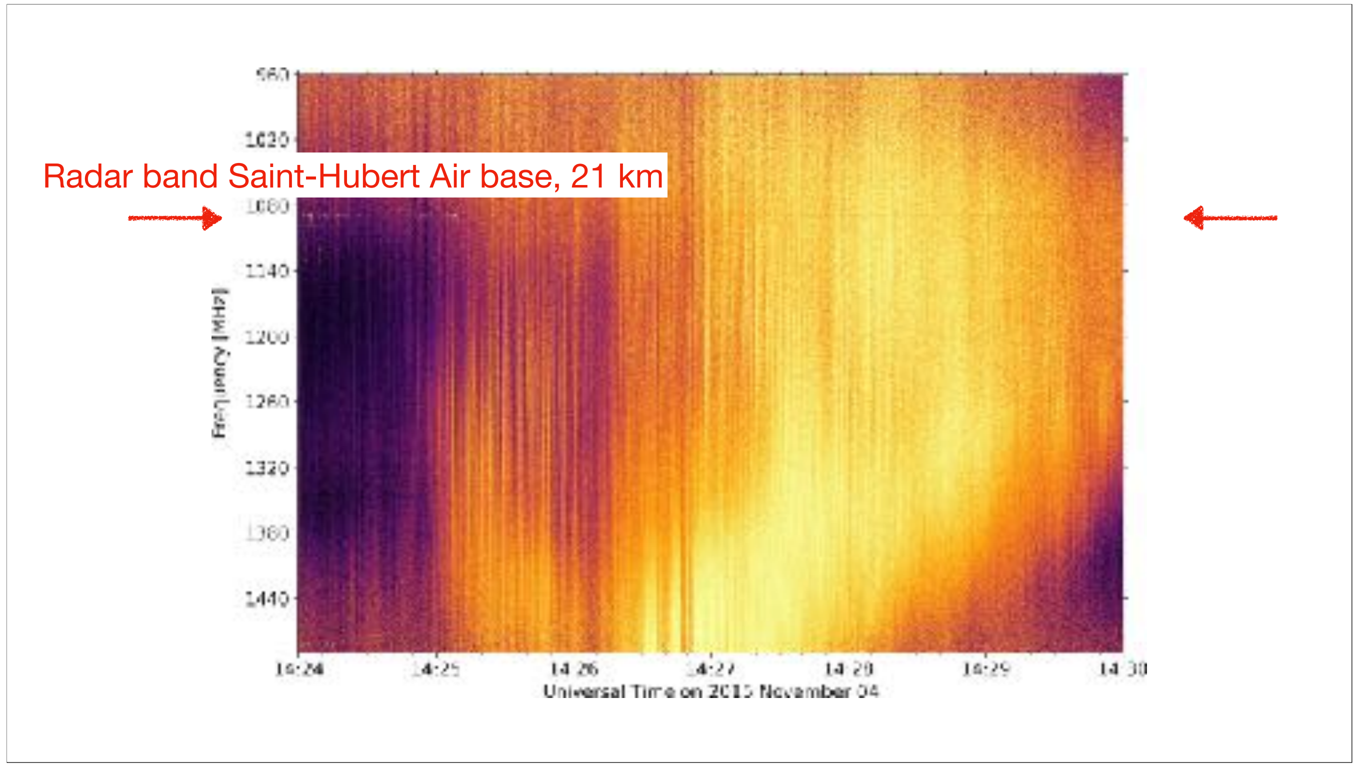
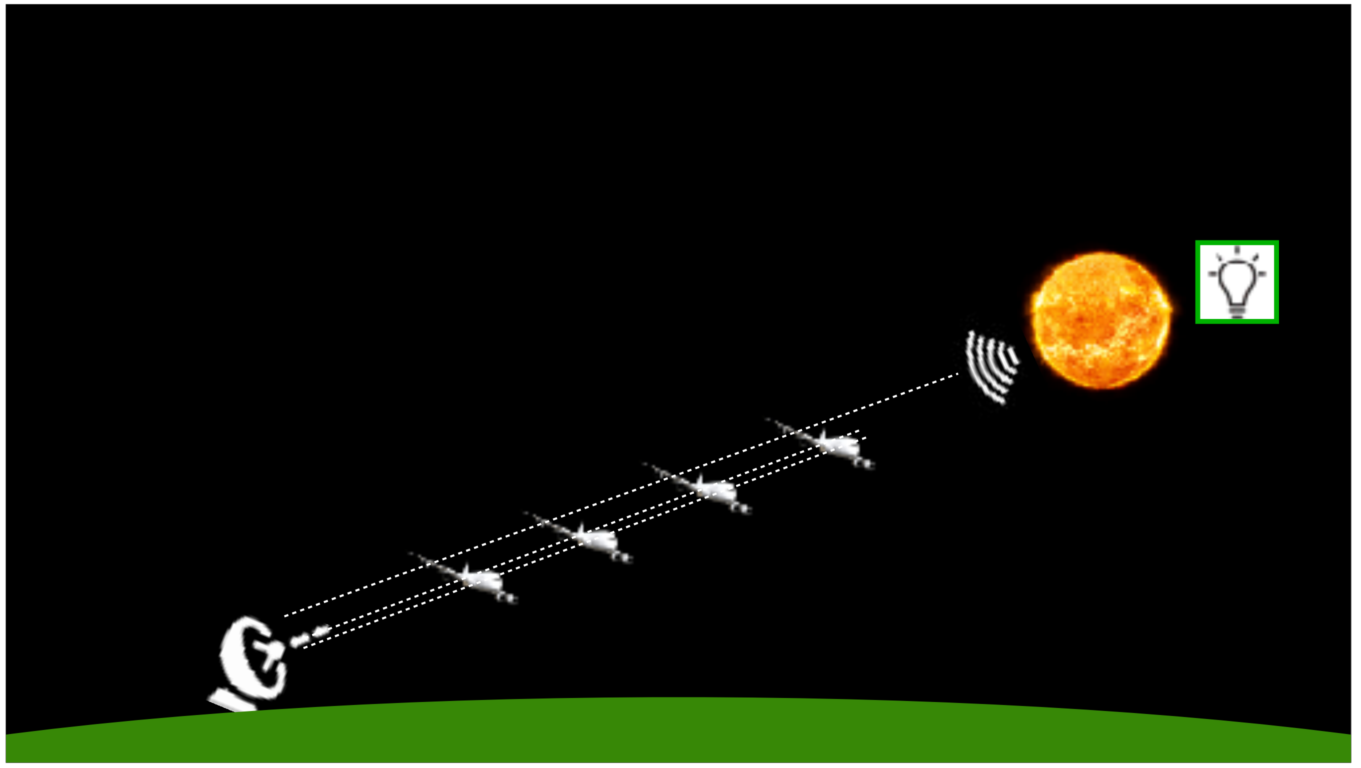


The output of the Sun was not in the noise level anymore. It was overruling the echo.

Surveillance radars ATC (1060 MHz) - Air Trafic control
Radar band saint-hubert air base, 21 km
Nov 4 2015



air traffic radars are affected when the Sun is low above the horizon

November 4,

Belgium: sunset on Nov 4
4:42 PM CET (UTC +1). This converts to 3:42 PM UTC.

Radar interference

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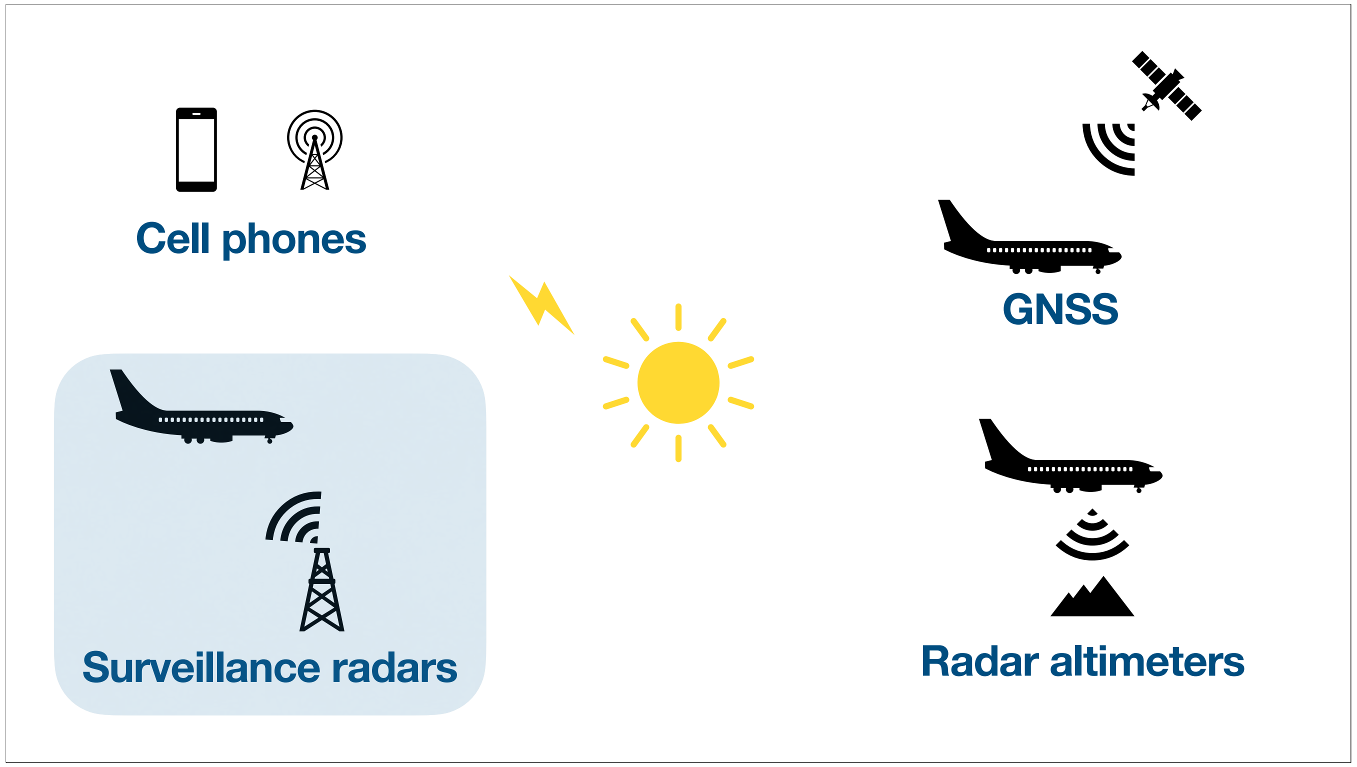
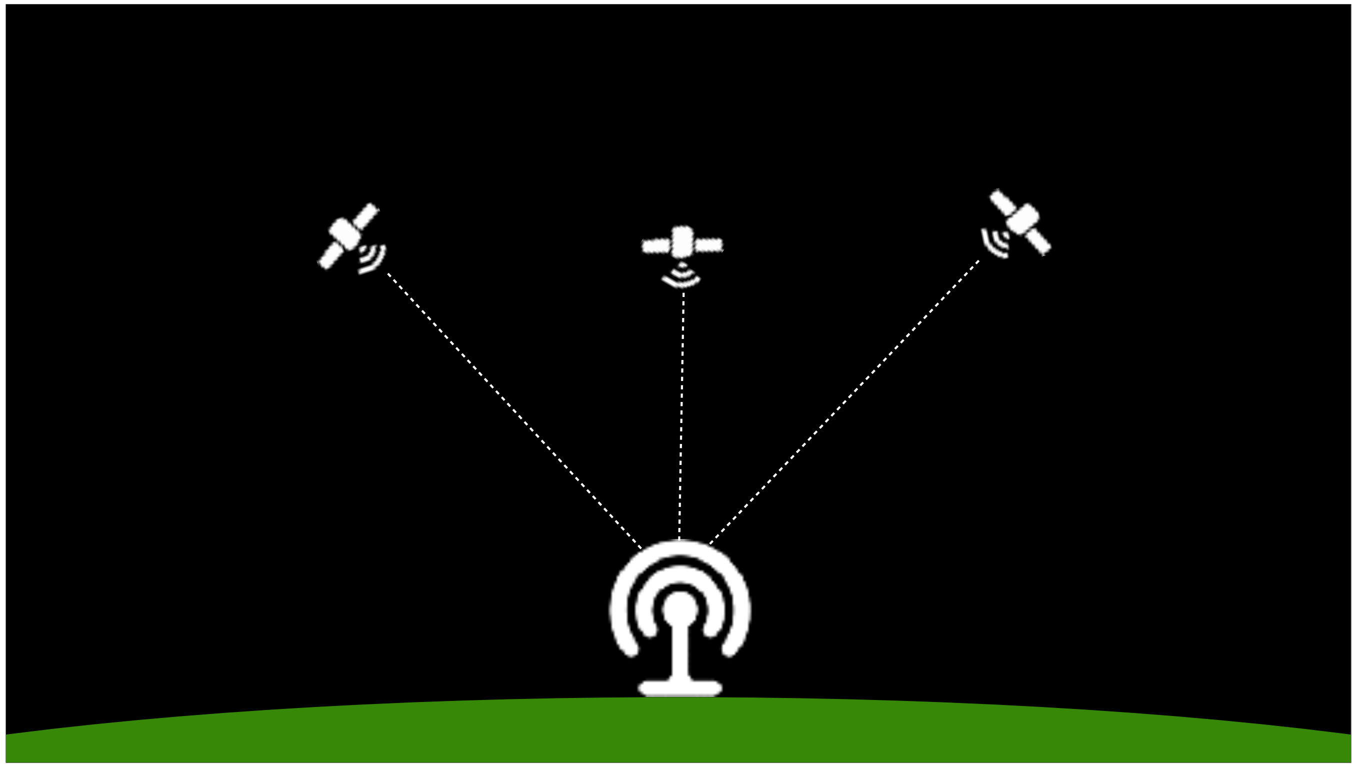


ground based GNSS systems will be more impacted when the Sun is close to the local zenith,

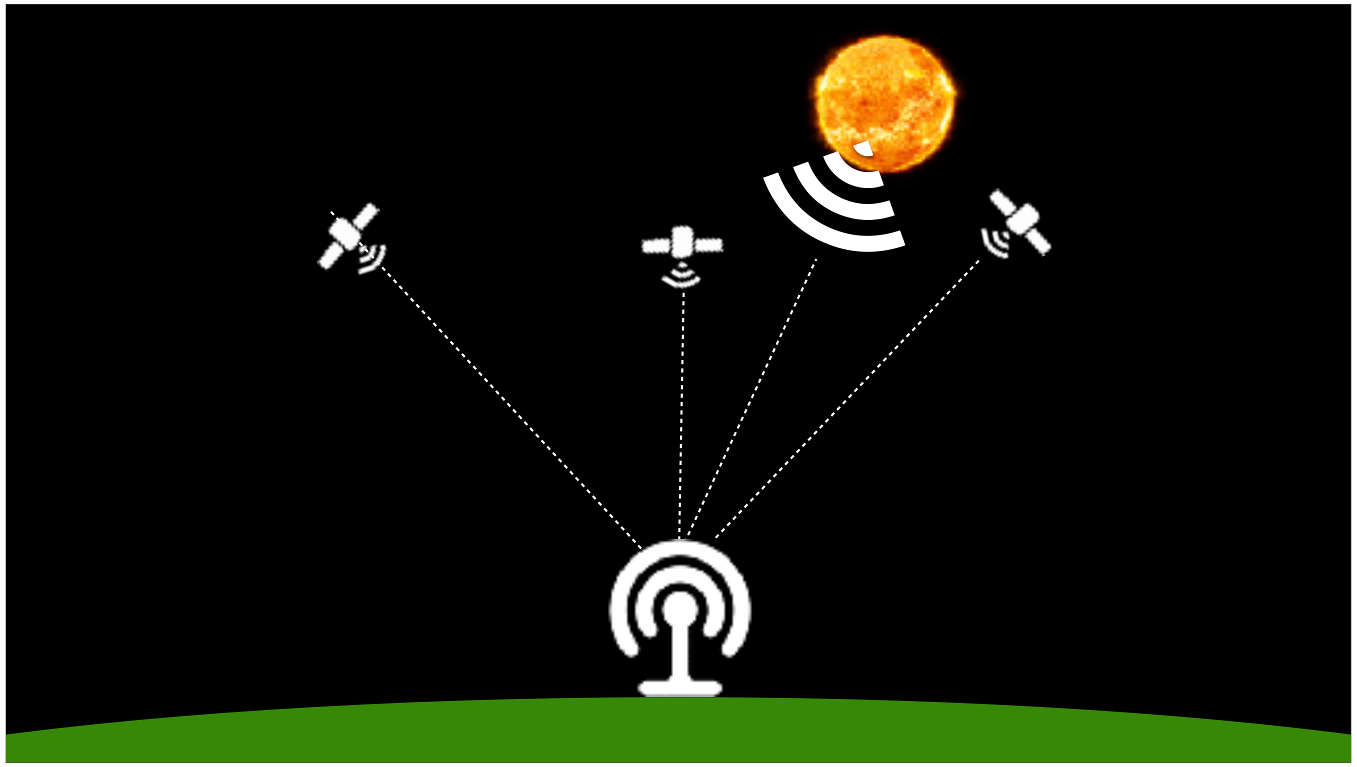


Within the noise

SRB can impact radar systems and GNSS but it a complete other way compared to flares. Flares, i.e. ionising radiation impact 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

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**.
GPS receiver ontvangt signalen die niet van een satelliet komen maar van de Zon. De GPS ontvanger maakt geen onderscheid tussen solar noise en satelliet signaal.



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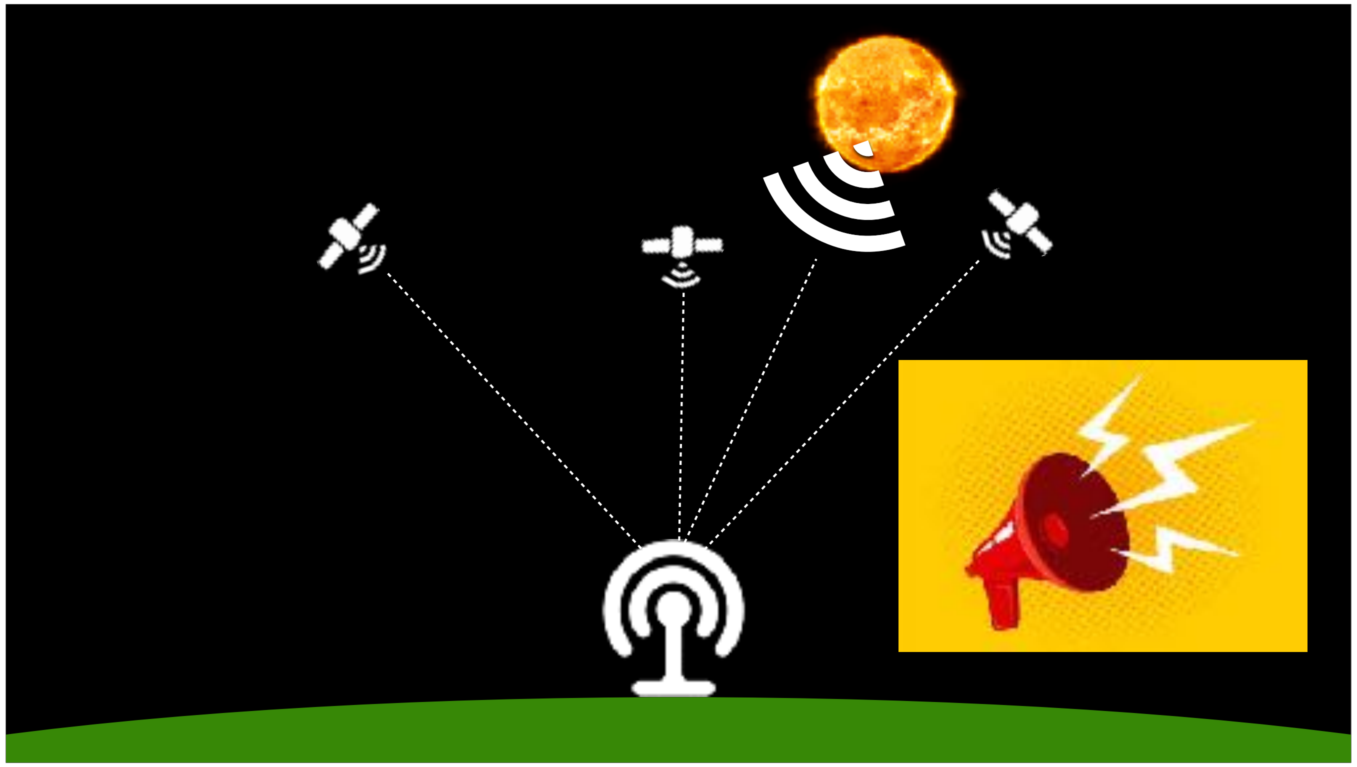

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