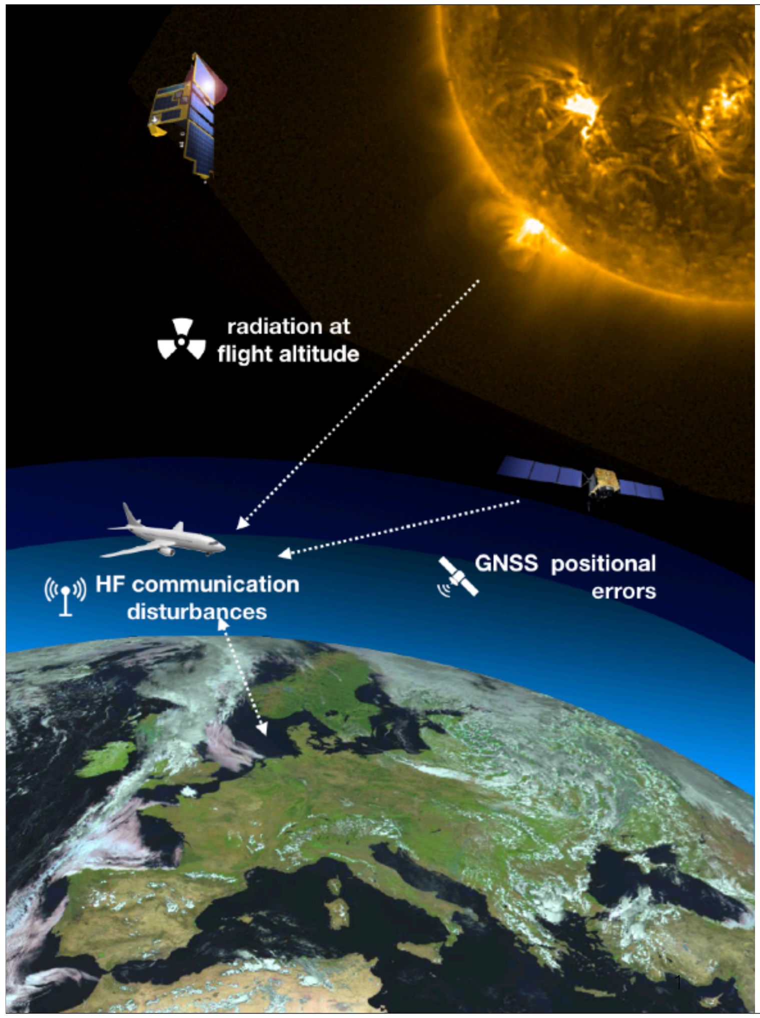


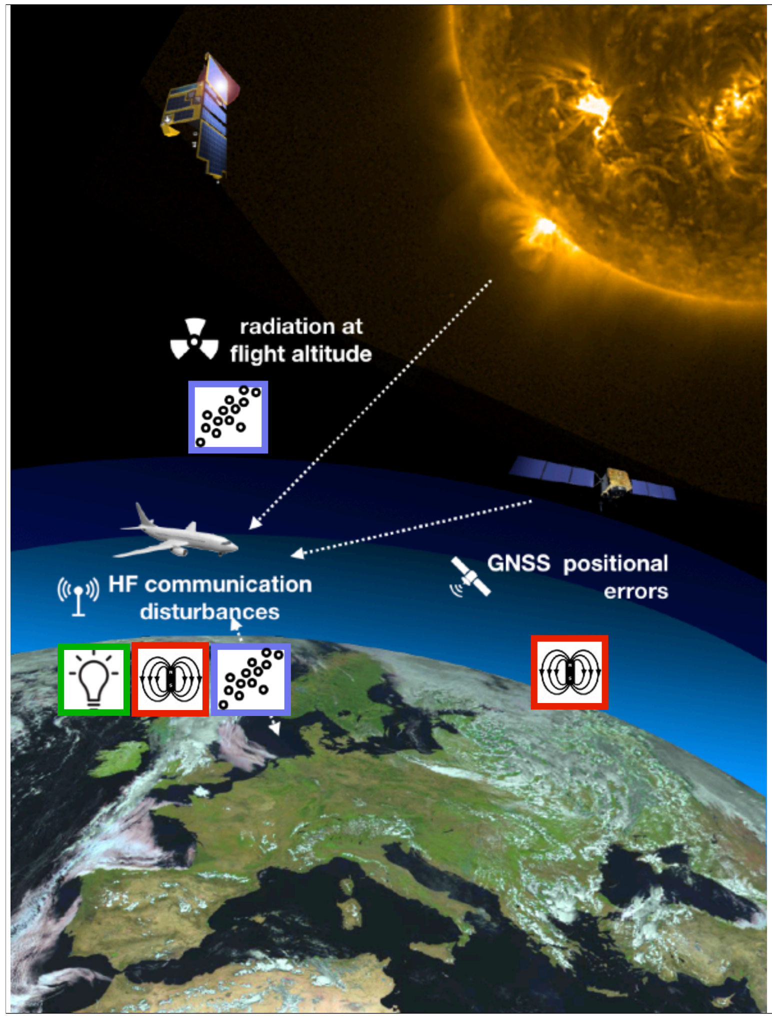
SWx for aviation

Petra.Vanlommel@oma.be

8 min	Days	Hour
X-ray: A,B,C,M,X	Kp: 0 - 9	Protons: Storm - Major Storm
Min to Hour	Day+	Hours to Days
Illuminated area	Polar Caps	Polar Caps High Altitude

PECASUS: Partnership for Excellence in Civil Aviation Space weather User Services
SWPC
ACFJ
Russia and China

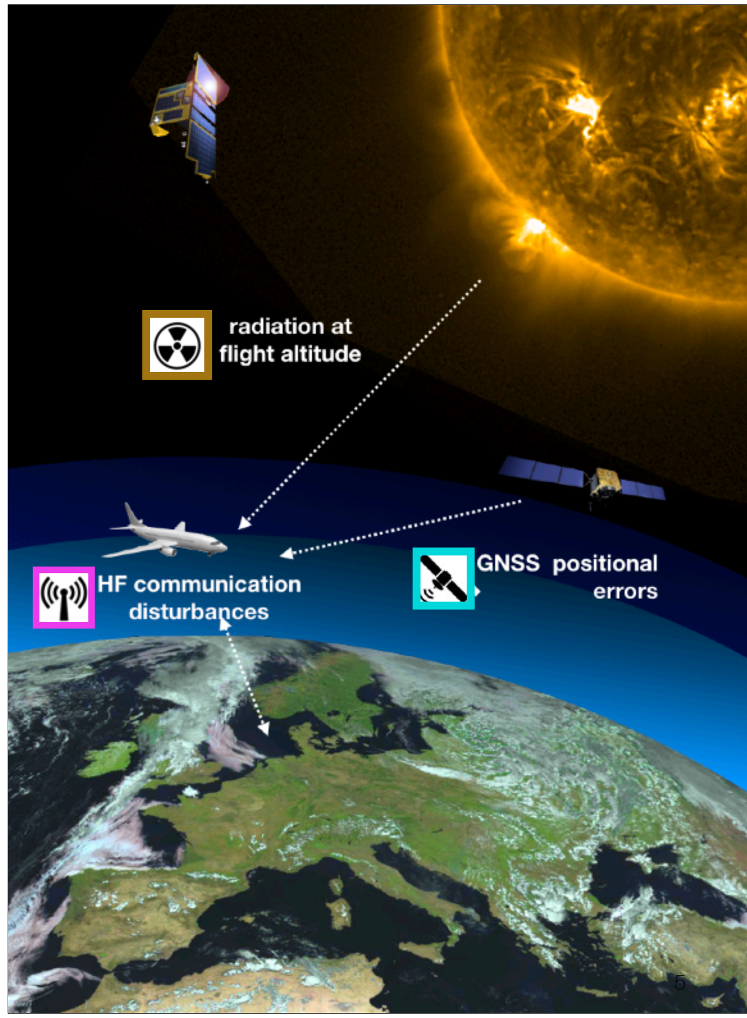
International Civil Aviation Organization



SPACE WEATHER IMPACTING AVIATION

Space weather impact our navigation and radio communication systems and can cause an increase of radiation levels at flight altitude.

A solar storm initiates space weather processes which impact our navigation and radio communication systems and can cause an increase of radiation levels at flight altitude.



Storm parameters

Thresholds

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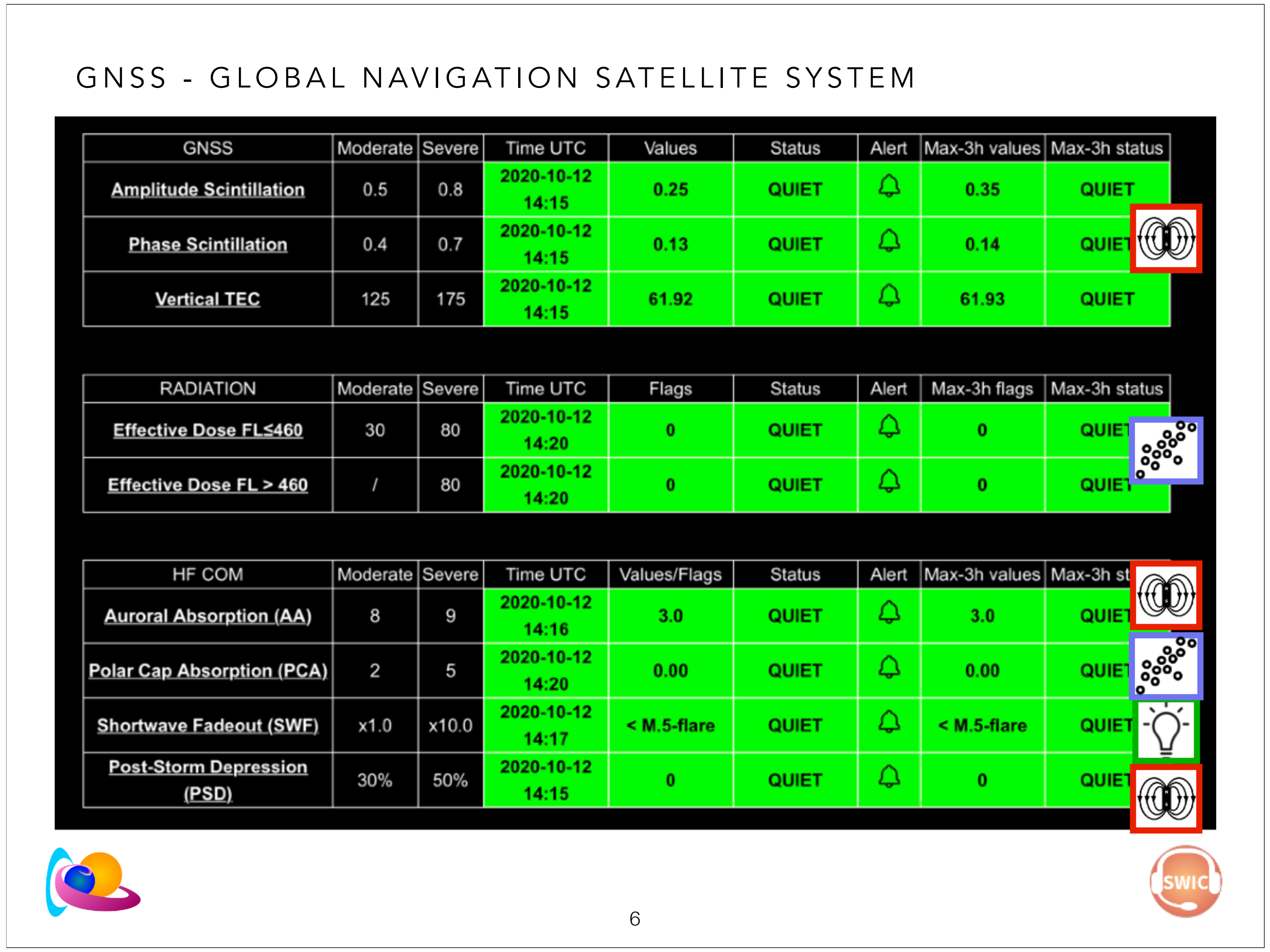

GNSS - GLOBAL NAVIGATION SATELLITE SYSTEM

GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
Phase Scintillation	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	QUIET
Vertical TEC	125	175	2020-10-12 14:15	61.92	QUIET		61.93	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL≤460	30	80	2020-10-12 14:20	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2020-10-12 14:20	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2020-10-12 14:16	3.0	QUIET		3.0	QUIET
Polar Cap Absorption (PCA)	2	5	2020-10-12 14:20	0.00	QUIET		0.00	QUIET
Shortwave Fadeout (SWF)	x1.0	x10.0	2020-10-12 14:17	< M.5-flare	QUIET		< M.5-flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET

Ionosphere is not needed, it's an inconvenient layer where the satellite signal has to go through.

One of the largest sources of error in Positioning Navigation and Timing (PNT) signals from GNSS satellites is due to the passage of the satellite signal through the relatively dense electron environment of the upper atmosphere. These errors are compensated for by GPS receivers that use an ionospheric delay correction model. During ionospheric storms, or periods where the ionosphere deviates significantly from normal conditions, these models may be inadequate and lead to uncorrected positioning errors. Precision navigation systems that autocorrect for the ionosphere, such as differential GPS, or GPS augmentation systems such as the Satellite-Based Augmentation System (SBAS) or Ground-Based Augmentation System (GBAS) are still susceptible to errors during severe ionospheric storms. GNSS positioning is also susceptible to interference from solar radio bursts in the ultra-high-frequency (UHF) range, leading to significant loss of satellite tracking for up to tens of minutes in severe cases.

https://www.swpc.noaa.gov/impacts/space-weather-and-gps-systems

There are several ways in which space weather impacts GPS function. GPS radio signals travel from the satellite to the receiver on the ground, passing through the Earth's ionosphere. The charged plasma of the ionosphere bends the path of the GPS radio signal similar to the way a lens bends the path of light. **In the absence of space weather, GPS systems compensate for the "average" or "quiet" ionosphere, using a model to calculate its effect on the accuracy of the positioning information.** But when the ionosphere is disturbed by a space weather event, the models are no longer accurate and the receivers are unable to calculate an accurate position based on the satellites overhead.

In calm conditions, single frequency GPS systems can provide position information with an accuracy of a meter or less. During a severe space weather storm, these errors can increase to tens of meters or more. Dual frequency GPS systems can provide position information accurate to a few centimeters. In this case the two different GPS signals are used to better characterize the ionosphere and remove its impact on the position calculation. But when the ionosphere becomes highly disturbed, the GPS receiver cannot lock on the satellite signal and position information becomes inaccurate.

https://www.swpc.noaa.gov/phenomena/solar-radiation-storm

…

Solar Radiation Storms cause several impacts near Earth. When energetic protons collide with satellites or humans in space, they can penetrate deep into the object that they collide with and cause damage to electronic circuits or biological DNA. During the more extreme Solar Radiation Storms, passengers and crew in high flying aircraft at high latitudes may be exposed to radiation risk. **Also, when the energetic protons collide with the atmosphere, they ionize the atoms and molecules thus creating free electrons.** These electrons create a layer near the bottom of the ionosphere that can absorb High Frequency (HF) radio waves making radio communication difficult or impossible.

…

```
SWX ADVISORY
DTG:               20231010/1836Z
SWXC:              PECASUS
ADVISORY NR:       2023/246
SWX EFFECT:        GNSS SEV
OBS SWX:           10/1800Z EQN EQS E030 - E060
FCST SWX +6 HR:    11/0000Z EQN EQS W060 - E000
FCST SWX +12 HR:   11/0600Z NOT AVBL
FCST SWX +18 HR:   11/1200Z NO SWX EXP
FCST SWX +24 HR:   11/1800Z NOT AVBL
RMK:               SPACE WEATHER EVENT (IONOSPHERIC
DISTURBANCE) IN PROGRESS. IMPACT ON GNSS PERFORMANCE
POSSIBLY LEADING TO LOSS OF GNSS SIGNALS AND/OR DEGRADATION
 OF TIMING AND POSITIONING PERFORMANCE.
NXT ADVISORY:      WILL BE ISSUED BY 20231011/0000Z=
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SWXC: PECASUS/SWPC/ACFJ/CRC
Type of advisory - MOD/SEV
Sequence - per domain, across centres - no combined domains
Forecast up to 24hr
Time +impacted area/NO SWX EXP/Not AVBL
Textual explanation: observed or expected impacts on technology, no details on physics, no mitigation actions

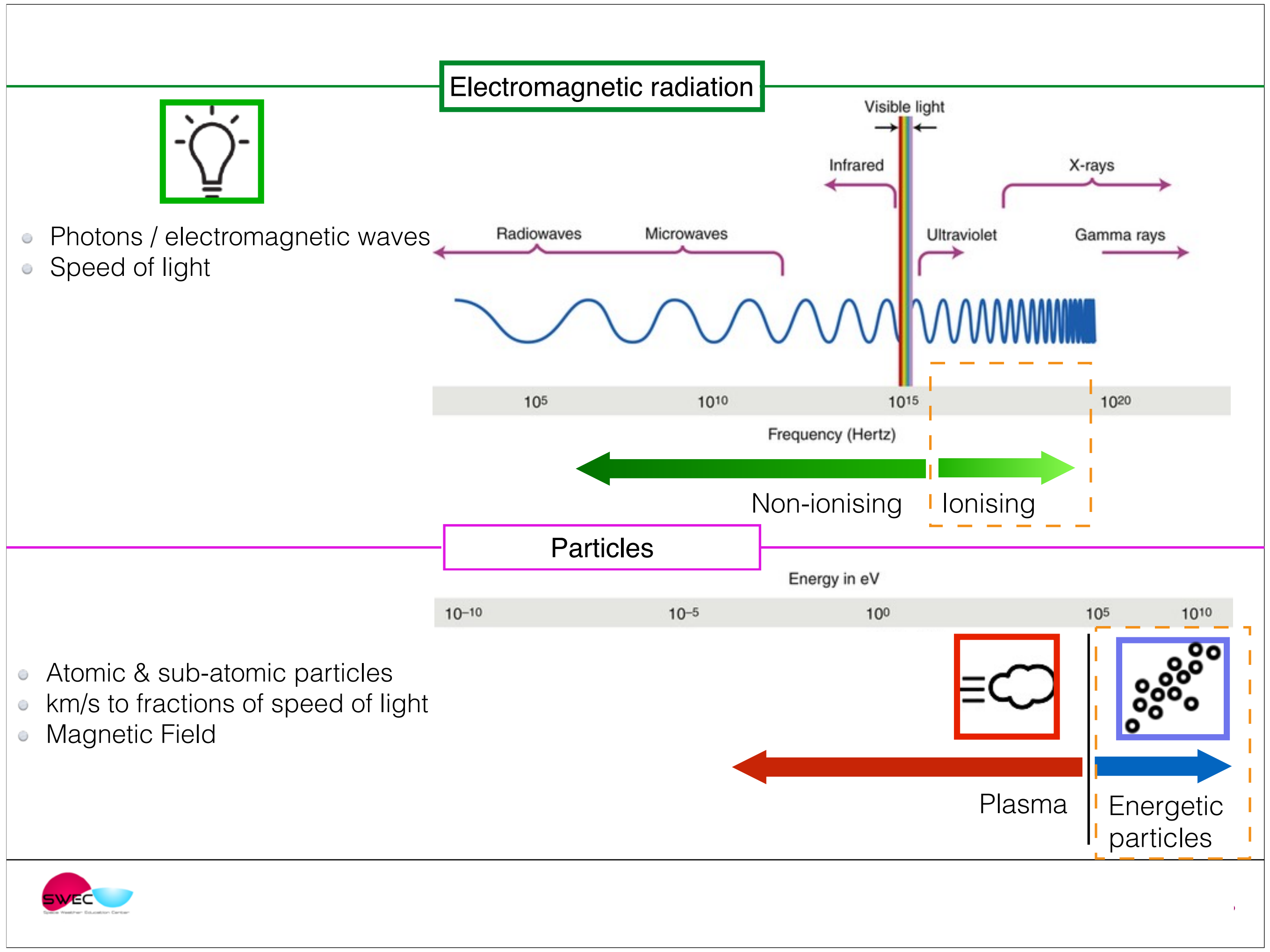
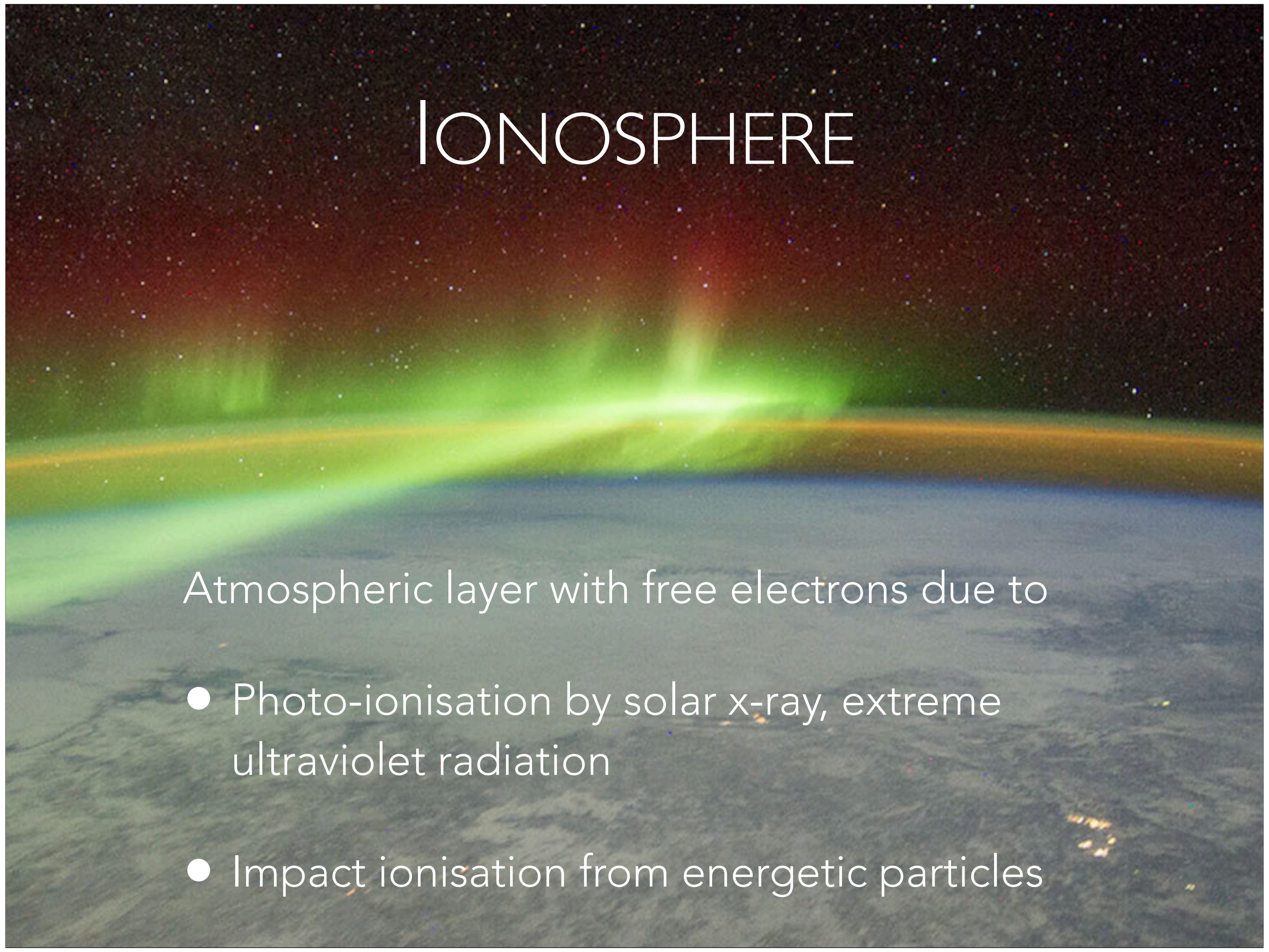


Photo-ionisation — green
Impact ionisation — blue

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.



To understand what the ionosphere does that affects these radio waves, we must first understand what the ionosphere is.

The picture shows the 'Northern Lights', seen from the International Space Station. The aurora makes the ionosphere visible to us.

The ionosphere is that part of the upper atmosphere where free electrons occur in sufficient density to have an appreciable influence on the propagation of radio frequency electromagnetic waves. This ionization depends primarily on the Sun and its activity. ionospheric structures and peak densities in the ionosphere vary greatly with time (sunspot cycle, seasonally, and diurnally), with geographical location (polar, auroral zones, mid-latitudes, and equatorial regions), and with certain solar-related ionospheric disturbances.

The major part of the ionization is produced by solar X-ray and ultraviolet radiation and by corpuscular radiation from the Sun. The most noticeable effect is seen as the Earth rotates with respect to the Sun; ionization increases in the sunlit atmosphere and decreases on the shadowed side. Although the Sun is the largest contributor toward the ionization, cosmic rays make a small contribution. Any atmospheric disturbance affects the distribution of the ionization.

The ionosphere is a **dynamic system controlled by** many parameters including **acoustic motions of the atmosphere, electromagnetic emissions, and variations in the geomagnetic field**. Because of its extreme sensitivity to atmospheric changes, the ionosphere is a very sensitive monitor of atmospheric events.

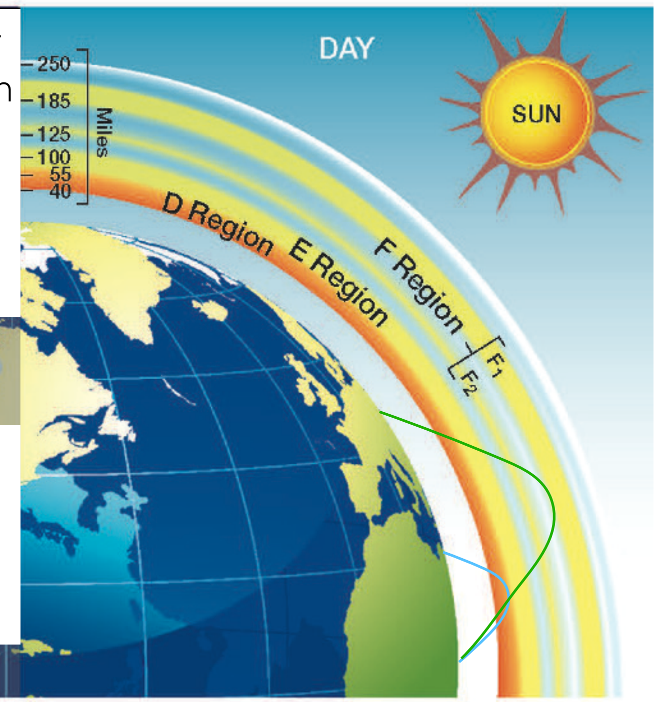
The most accurate way of measuring the ionosphere is with a ground-based ionosonde, which records data as ionograms.

RADIO WAVES & IONOSPHERE

The electron content of each layer defines a critical frequency which in turn affects the refractive index of the medium

$$f_p \propto \sqrt{n_o} \qquad \Big| \qquad n = \sqrt{1 - \frac{f_p^2}{f^2}}$$

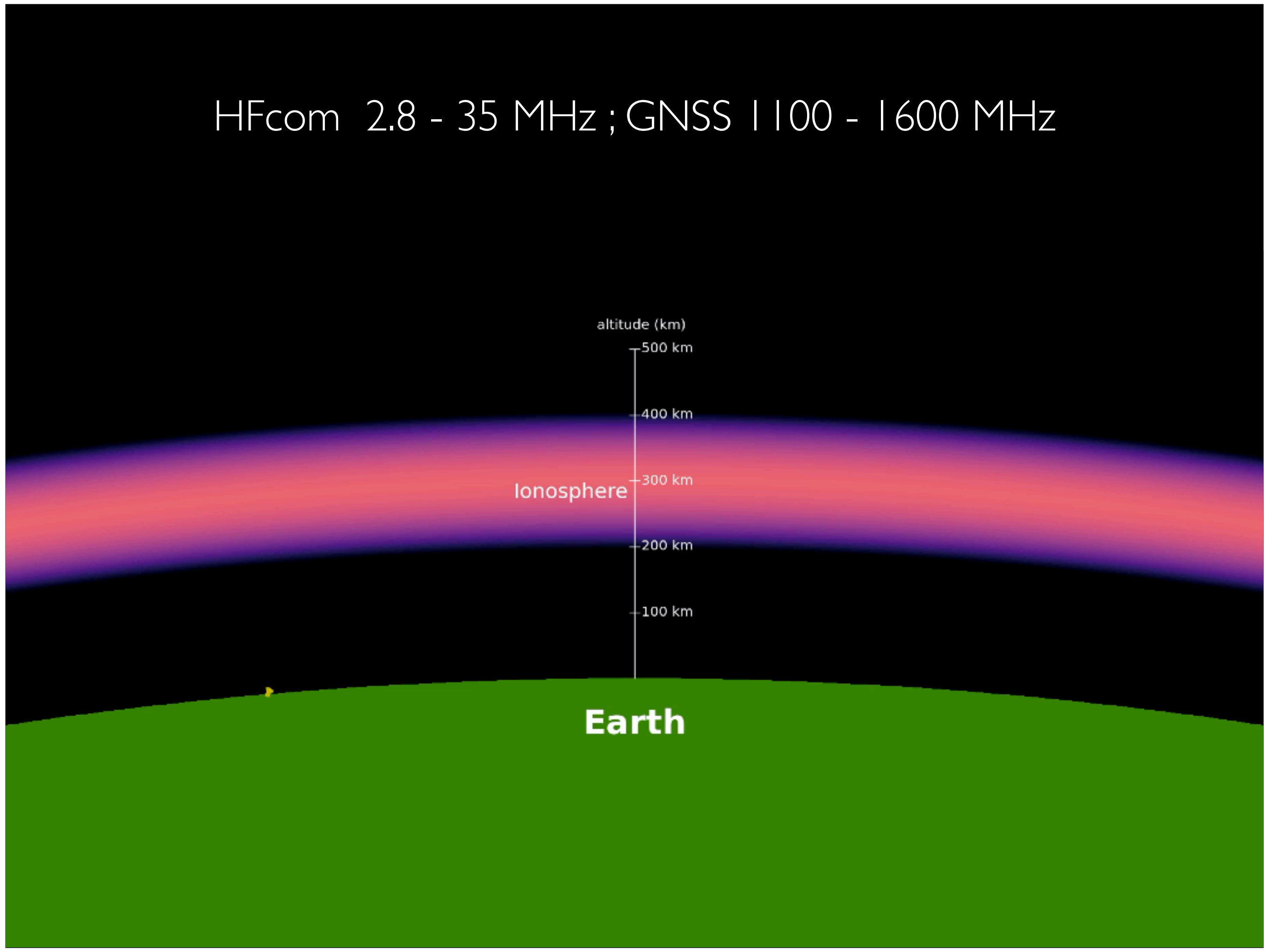
Each layer will reflect or absorb or let pass radio waves depending on their frequencies and on the characteristic frequency.



Both GNSS and HF com use radio waves —> how do radio waves behave in an ionised medium

n0, electron content —> critical frequency f0F2 or fp or characteristic frequency—> refractive index

In physics, refraction is the change in direction of a wave passing from one medium to another or from a gradual change in the medium.



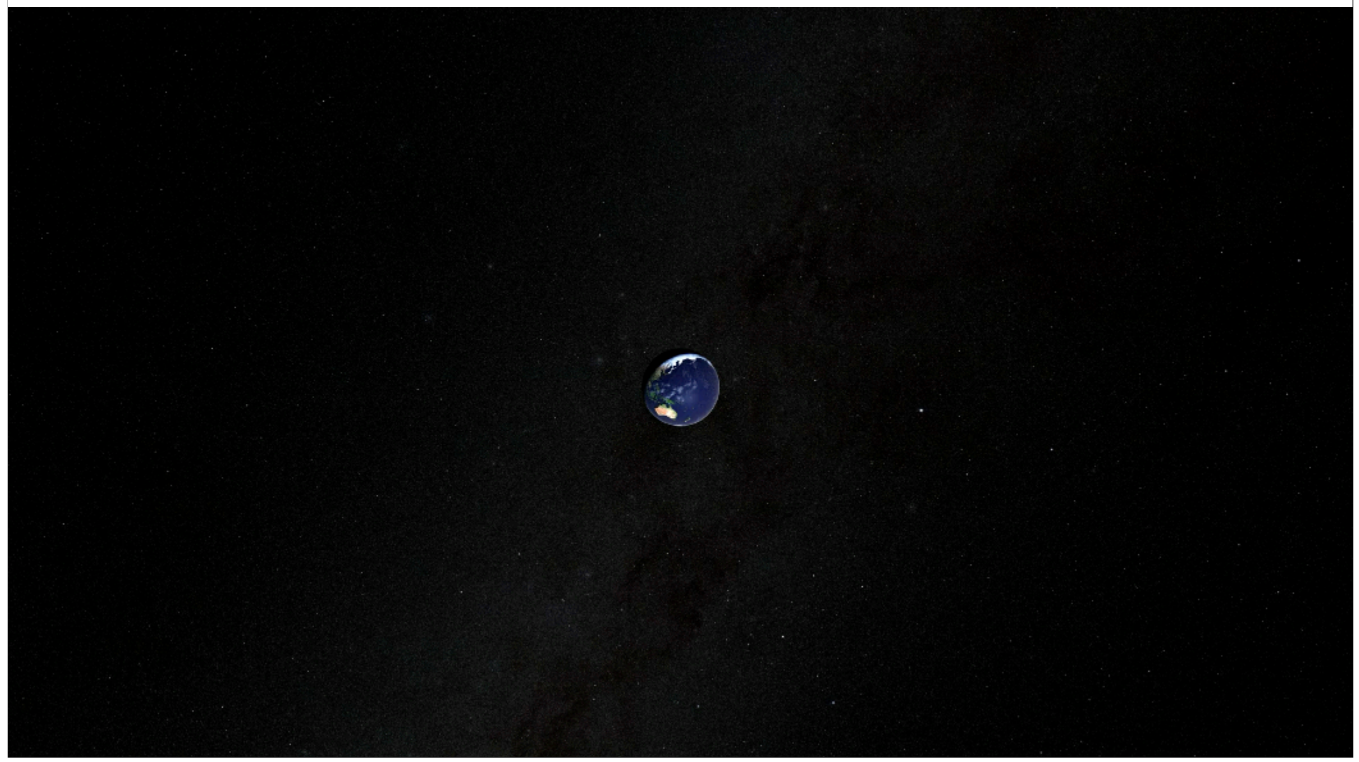
The ionosphere is the key-layer for HF communication and GNSS performance: or radio waves are reflected at, or pass through the ionosphere. The reflection is used for long distance communications.

The ionosphere has the ability to reflect radio waves. If the degree of ionisation would be zero, no radio waves would be reflected and all would pass.

Ionisation can change over time.
Ionisation is not the same everywhere.

During the night, the ionisation decreases - the skill to reflect drops.
—> also LF goes through —> Maximum Usable Frequency, MUF decreases.

MAGNETOSPHERE-IONOSPHERE COUPLING

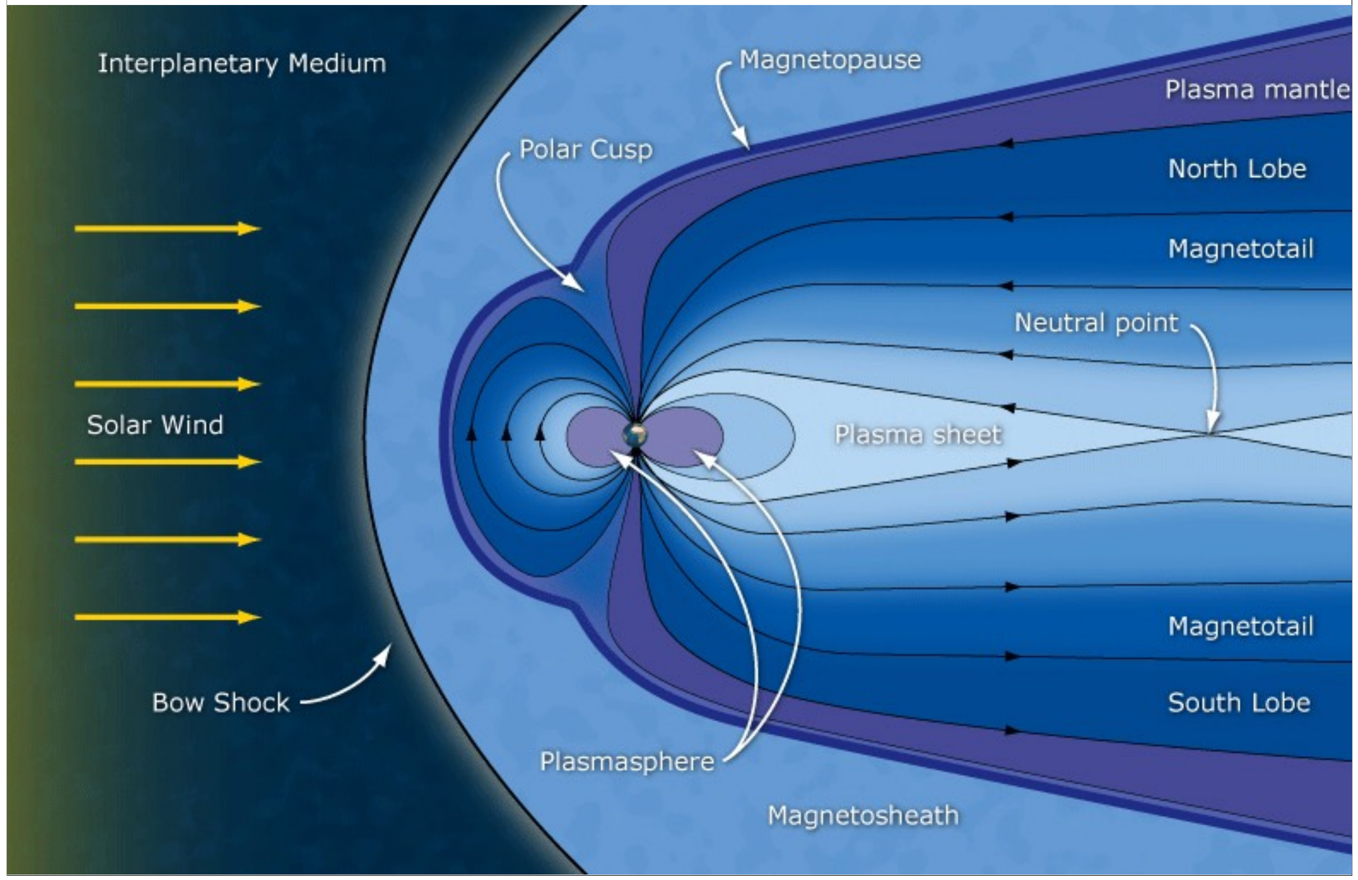


The geomagnetic field

The Earth has an internal magnetic field. That field is produced in the Earth’s interior. It is changing slowly. (The magnetic poles move with a speed of about 10 km/year.)
It has this particular form due to the solar wind.

The magnetosphere is the region around Earth that is dominated by the geomagnetic field. The magnetospheric plasma originates in part in the ionosphere; the rest is captured solar wind material.

Magnetosphere-ionosphere coupling



Earth magnetic field 25000 – 65000 nT
Magnetic field strengths within sunspots are thousands of times more intense than Earth's average surface field

The solar wind is a magnetized plasma. It encounters the environment of the Earth, which also turns out to be a magnetized plasma. Indeed, the Earth has an internal magnetic field. That field is produced in the Earth's interior. It is changing slowly. (The magnetic poles move with a speed of about 10 km/year.)

The magnetosphere is the region around Earth that is dominated by the geomagnetic field. The magnetospheric plasma originates in part in the ionosphere; the rest is captured solar wind material.

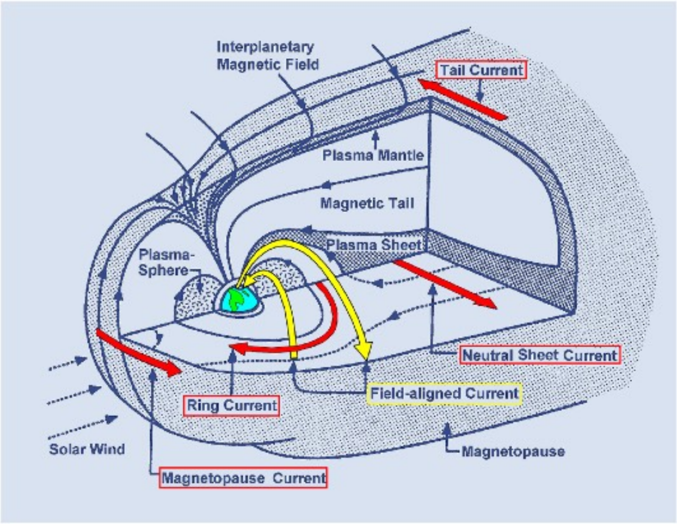
Magnetosphere is a highly dynamical system
https://www.researchgate.net/figure/Structure-of-Earth-magnetosphere-with-magnetopotentials-in-blue-inner-radiation-belt-in_fig3_351130787
Structure of Earth magnetosphere with magnetopotentials in blue, inner radiation belt in green, and outer radiation belt in red.

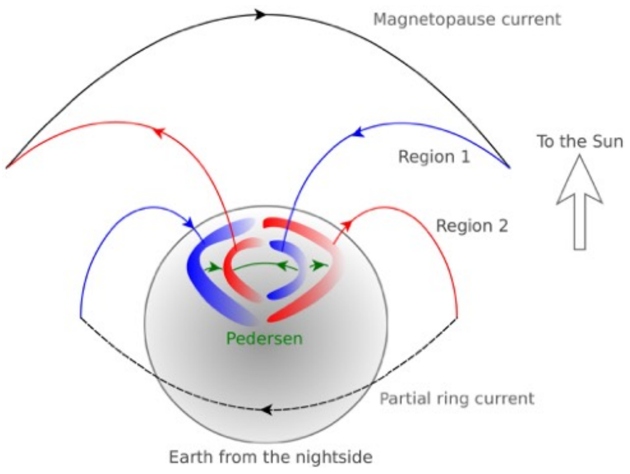
The magnetosphere consists of a (1) bow shock, where the solar wind (the stream of protons from the Sun) is slowed; (2) the magnetosheath behind the bow shock that contains thermalized solar plasma; (3) the magnetopause, where the thermalized solar plasma pressure is balanced by the plasma pressure generated by the magnetosphere; (4) the magnetotail, where the magnetic field is stretched out by the solar wind behind the dipole; and (5) the plasmasphere, where plasma is trapped by the magnetic field. The radiation belts are formed in the plasmasphere of the Earth's magnetosphere.

Charged particles can move rather freely along field lines and therefore are good electric conductors. Electric currents flow along the field lines and connect magnetosphere and ionosphere. Therefore every electric feature in the magnetosphere has an "image" in the ionosphere, and conversely. We identify the following regions:

- Magnetopause ↔ footpoints of the cusps
- Tail lobes ↔ polar caps
- Plasma sheet ↔ auroral oval
- Plasmasphere ↔ ionosphere at low latitude

MAGNETOSPHERE-IONOSPHERE COUPLING





Currents
Ampères law : circulation of magnetic field = enclosed electric current —> sheet current

Magnetosphere-ionosphere coupling
Field aligned currents along the magnetic field lines, connect the magnetospheric currents with ionospheric currents. The Pedersen and Hall currents are two main currents in the lower ionosphere. They are localized in the ionospheric D and E regions.
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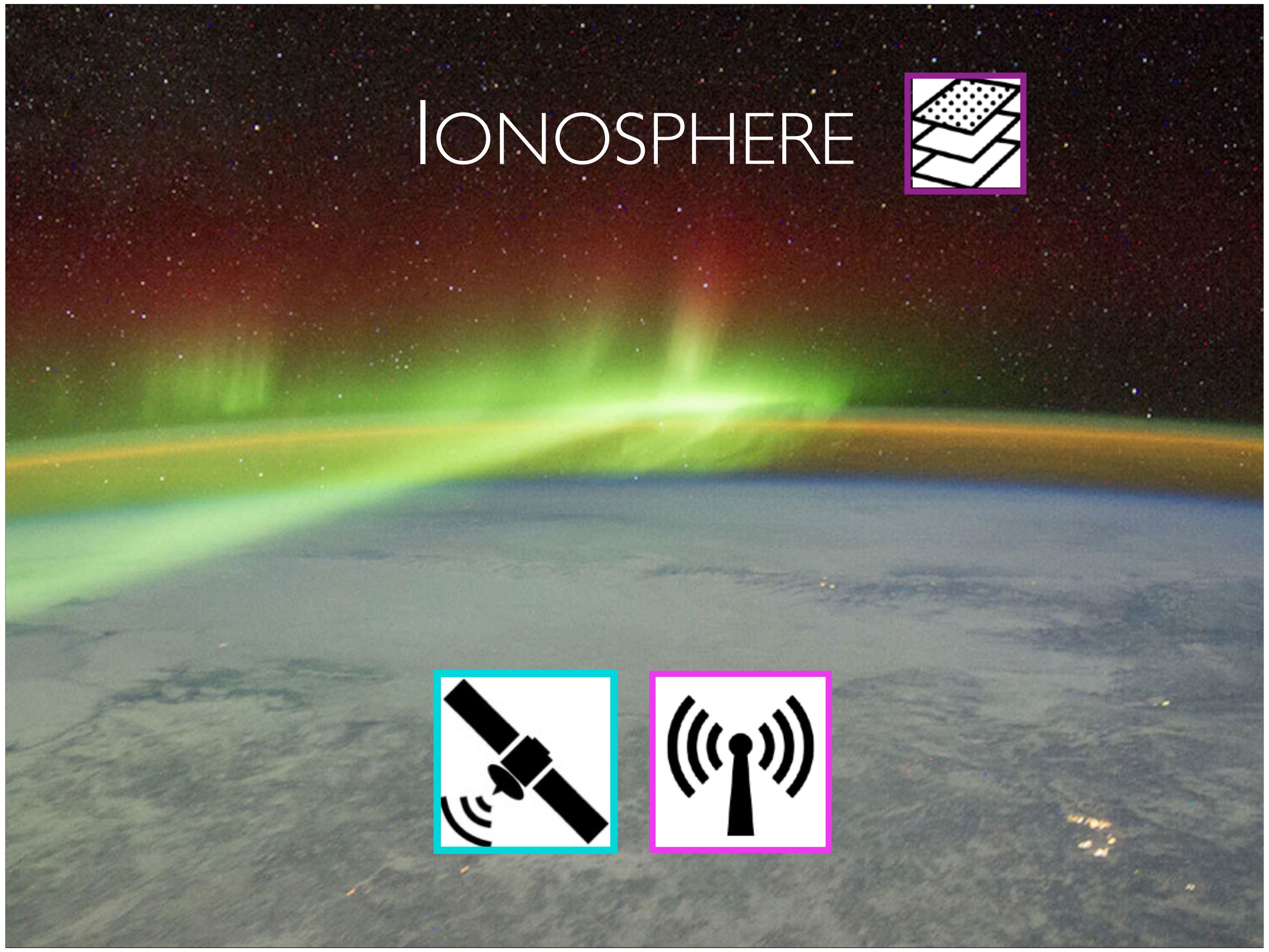
Current sheets in plasmas store energy by increasing the energy density of the magnetic field. Many plasma instabilities arise near strong current sheets, which are prone to collapse, causing magnetic reconnection and rapidly releasing the stored energy.

Between field lines there can always be changes in field strength or direction. Consequently, electric currents flow there:

Magnetopause current
Neutral sheet current
Ring current

The magnetopause interfaces two regions with different magnetic field. It therefore must be a current sheet : it carries the magnetopause current responsible for the change in magnetic field.
When solar wind comes close to the Earth, it cannot easily penetrate the Earth's internally generated magnetospheric magnetic field. The magnetopause, a surface boundary separating the two different regions, is formed. The kinetic pressure of the solar wind compresses the terrestrial magnetic field on the dayside, and this is associated with magnetopause current flowing across the magnetopause.

Neem het voorbeeld van de ring current met kruisjes en puntjes



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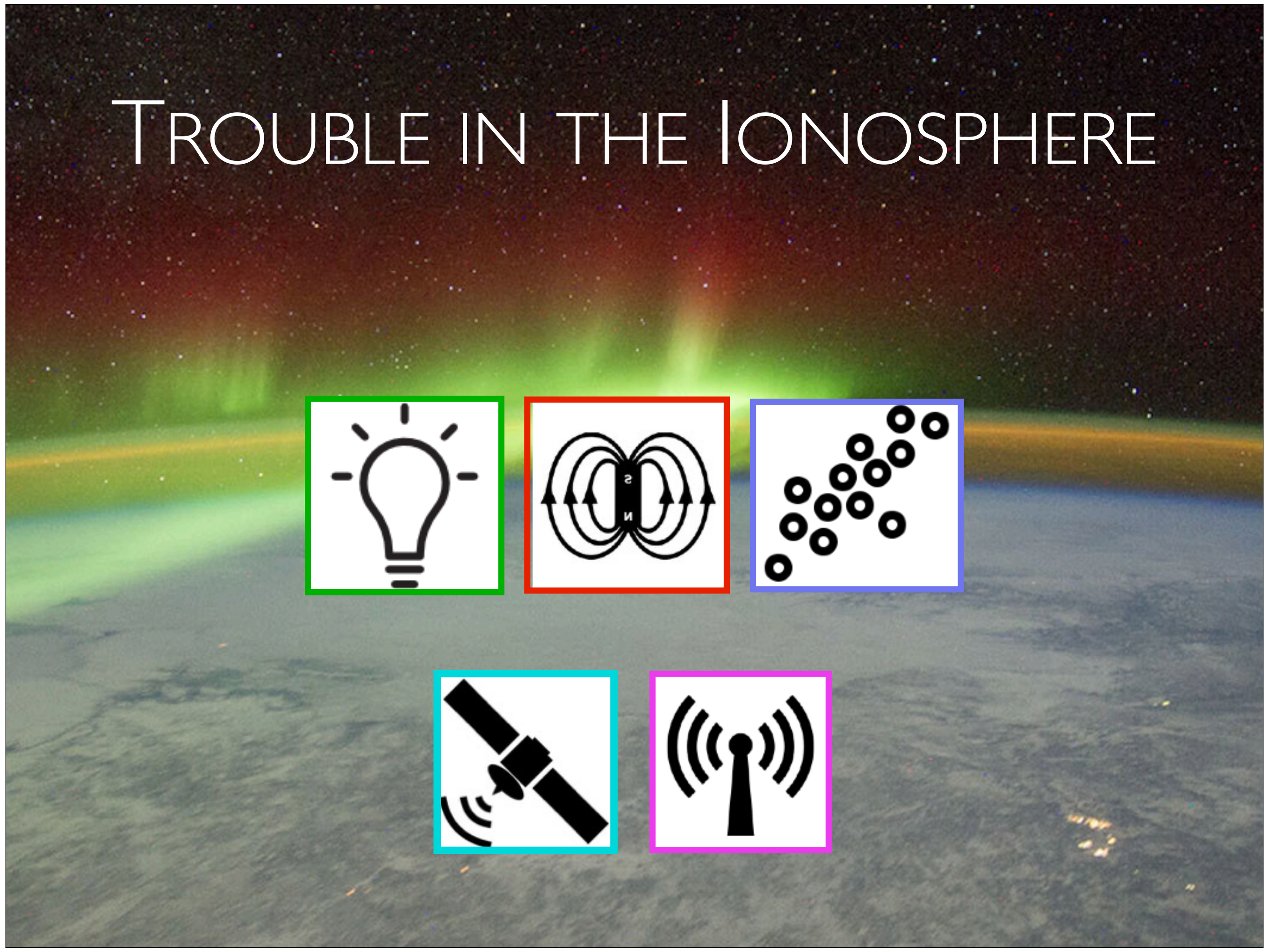
The most accurate way of measuring the ionosphere is with a ground-based ionosonde, which records data as ionograms.



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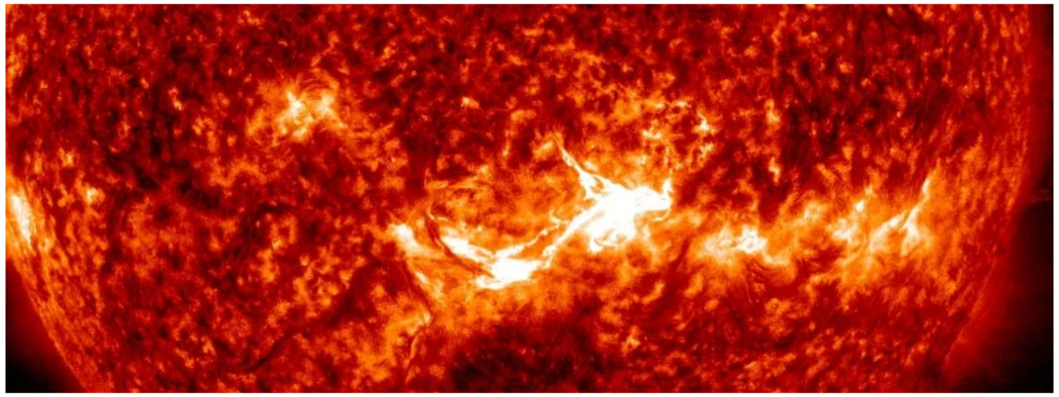
Solar and heliospheric storms impacting aviation

CASE STUDY - April 23, 2023



GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
Phase Scintillation	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	QUIET
Vertical TEC	125	175	2020-10-12 14:15	61.92	QUIET		61.93	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL≤460	30	80	2020-10-12 14:20	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2020-10-12 14:20	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2020-10-12 14:16	3.0	QUIET		3.0	QUIET
Polar Cap Absorption (PCA)	2	5	2020-10-12 14:20	0.00	QUIET		0.00	QUIET
Shortwave Fadeout (SWF)	x1.0	x10.0	2020-10-12 14:17	< M.5-flare	QUIET		< M.5-flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET

Ionosphere is needed for long distance HF communication which makes use of the reflective capability of the ionosphere. The ionosphere acts as a mirror.

AA, PCA, SWF are absorption events – low frequencies
PSD reduces the range of frequencies available – high frequencies are not available.

HF Com
If you have a strong radio burst in HF, your MUF might be full of solar noise and in practice not usable. But SRB are not taken into account by ICAO

Similar, Solar Radio Bursts can impact also GNSS by adding noise.

April 23, 17 UT

05/03/2024 06:53 UTC

STATUS
SBC

MAIN
GNSS
RADIATION
HF COM
ARCHIVE

Advisory
Daily Brief
Data
Procedure
Portfolio
ICAO Docs

RWC

Contact
Mute status

-24h -12h -6h -3h -1h -5m Submit 2023-04-23 17:00 now +5m +1h +3h +6h +12h +24h

PECASUS DASHBOARD on 2023-04-23 17:00 UTC

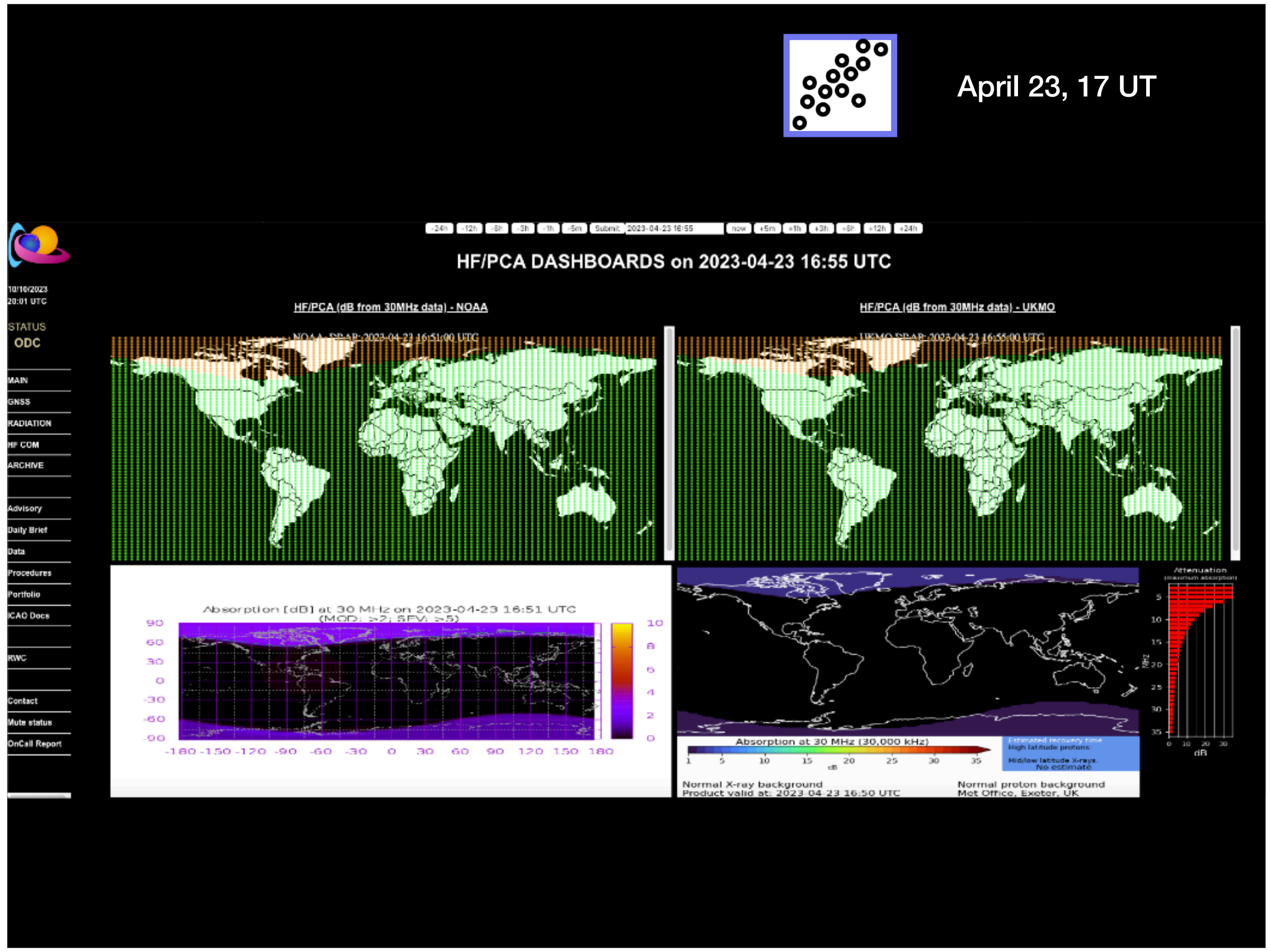
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2023-04-23 17:00	0.25	QUIET		0.36	QUIET
Phase Scintillation	0.4	0.7	2023-04-23 17:00	0.12	QUIET		0.14	QUIET
Vertical TEC	125	175	2023-04-23 17:00	96.98	QUIET		96.98	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL ≤ 460	30	80	2023-04-23 17:00	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2023-04-23 17:00	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2023-04-23 17:00	5.3	QUIET		5.3	QUIET
Polar Cap Absorption (PCA)	2	5	2023-04-23 17:00	2.75	MODERATE		2.94	MODERATE
Shortwave Fadeout (SWF)	x1.0	x10.0	2023-04-23 17:00	< M5 flare	QUIET		< M5 flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2023-04-23 17:00	0	QUIET		0	QUIET

Sound alarm is triggered when MOD or SEV thresholds are exceeded or in case of data outages.

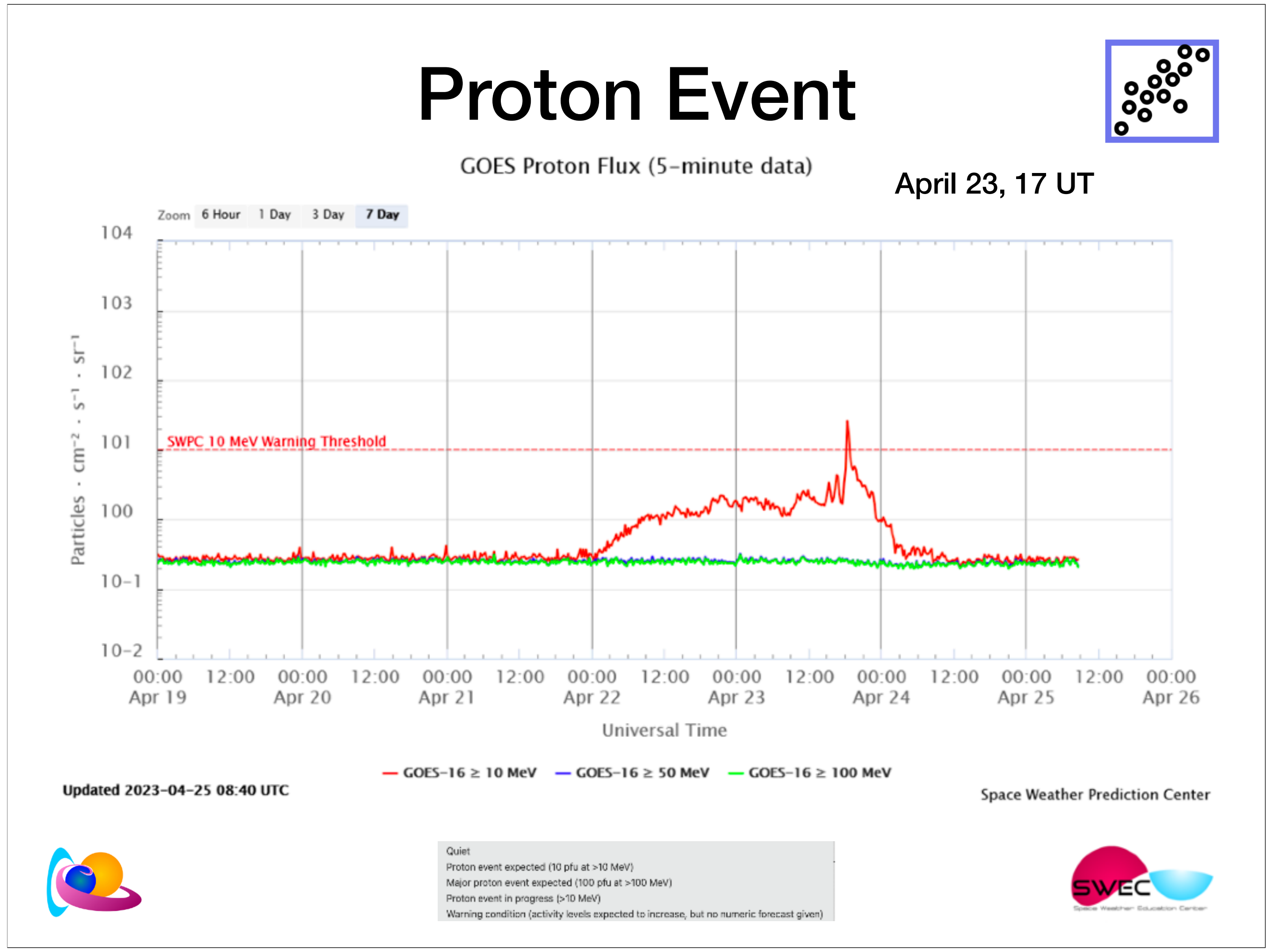
19LT —> 17 UTC



DRAP model

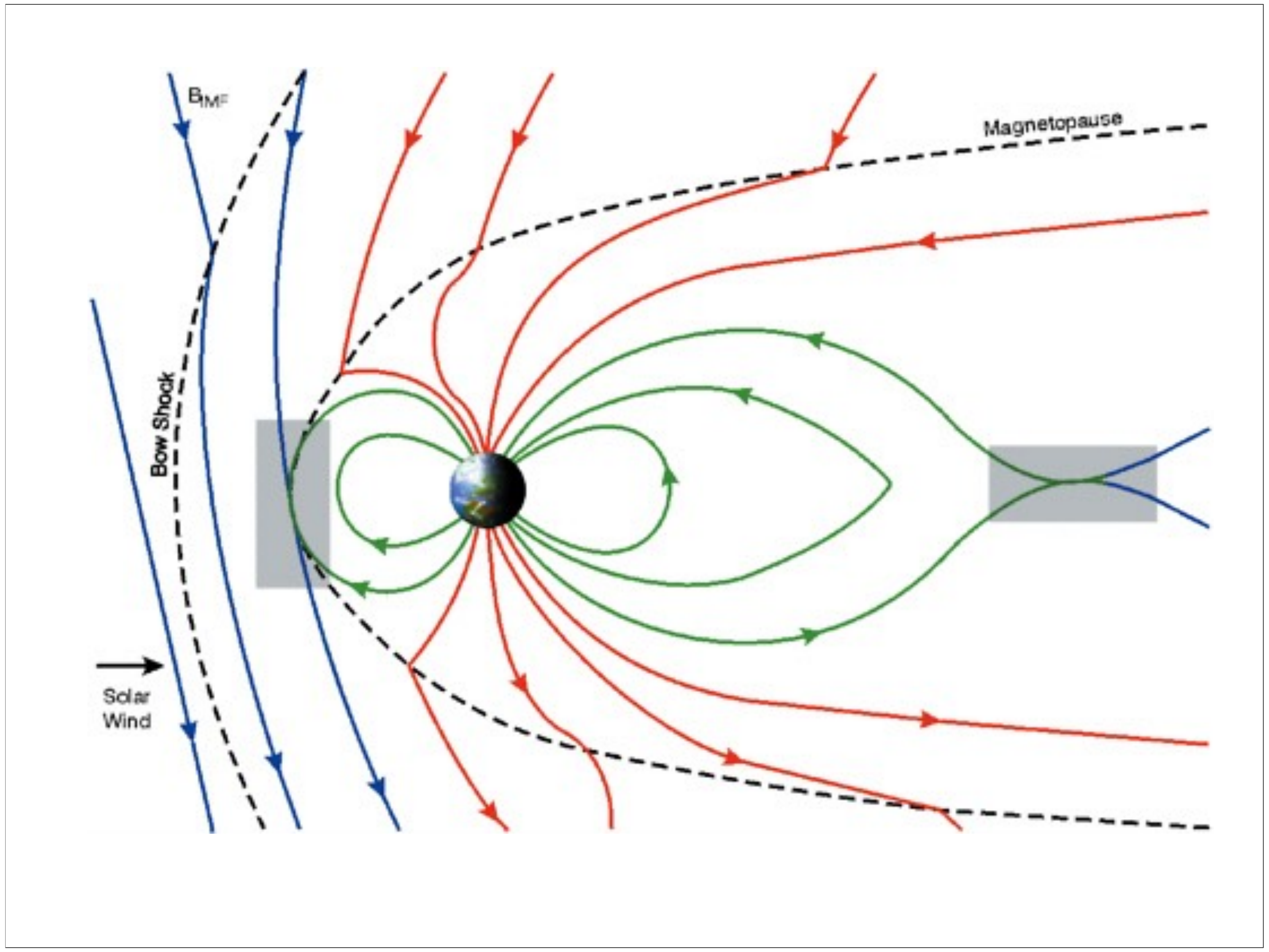
D-Region Absorption Predictions
Map giving info on spatial extend and which frequencies are impacted

PCA - scherpe overgang - bruut over van open naar gesloten magnetische veldlijnen.
De deeltjes moeten een open route (open veldlijn) hebben om af te dalen naar de D-laag



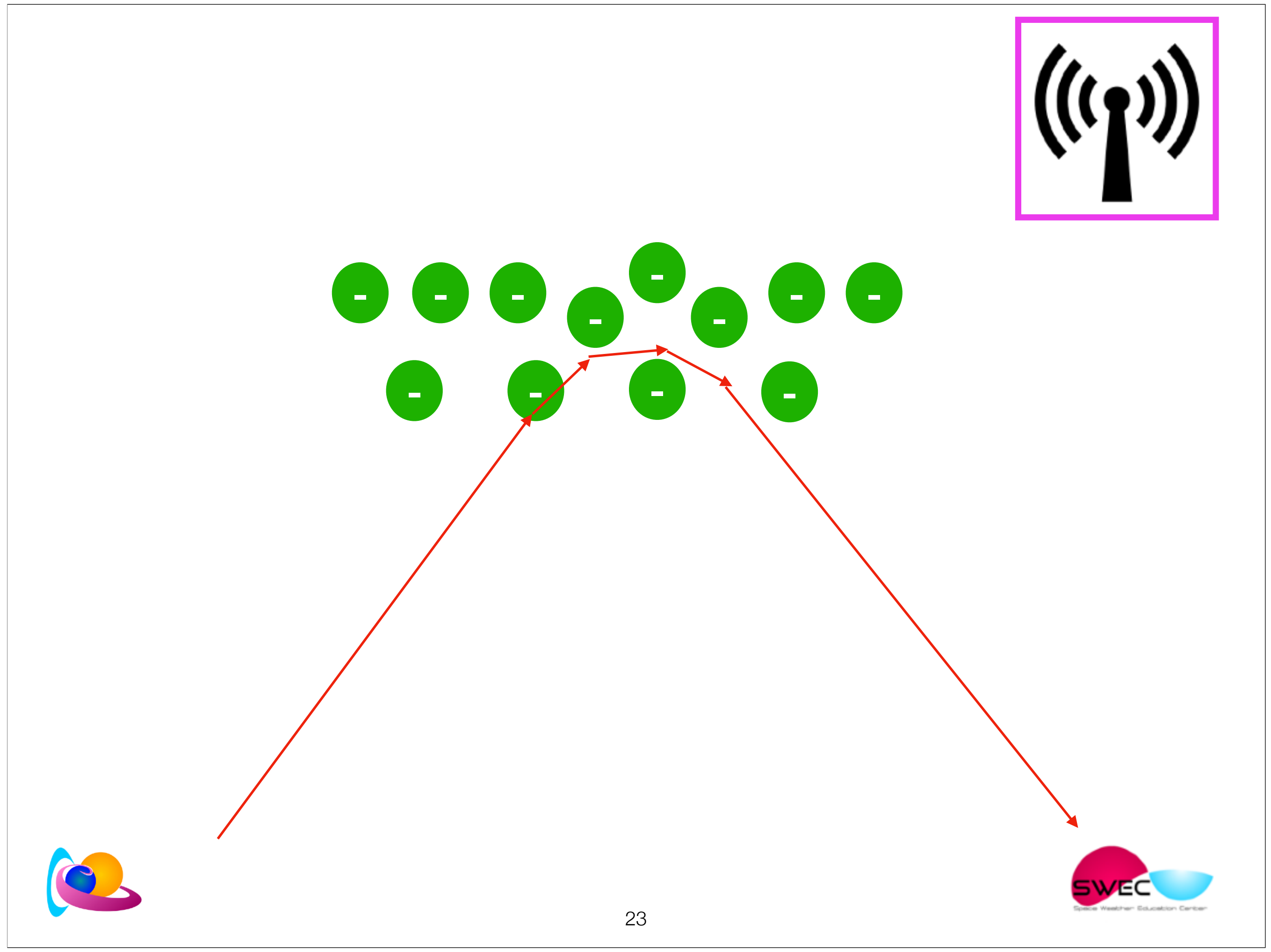
A shock was recorded in the solar wind parameters on 23 April at 17:00UTC (DSCOVR ; graph). It marked the **somewhat (a few hours) earlier-than-expected arrival of the interplanetary coronal mass ejection (ICME)**. **The passage of the shock briefly drove the already enhanced greater than 10 MeV proton flux finally above the proton event threshold (10 pfu)**, with a maximum of 26 pfu recorded at 18:20UTC (graph underneath). This is called an Energetic Storm Particles event (ESP), and originates from the acceleration of charged particles by a fast, usually ICME-driven shock in interplanetary space (e.g. Ameri et al. 2023). The proton flux drops sharply after the **shock** passage, as was the case here.

Shock pushes



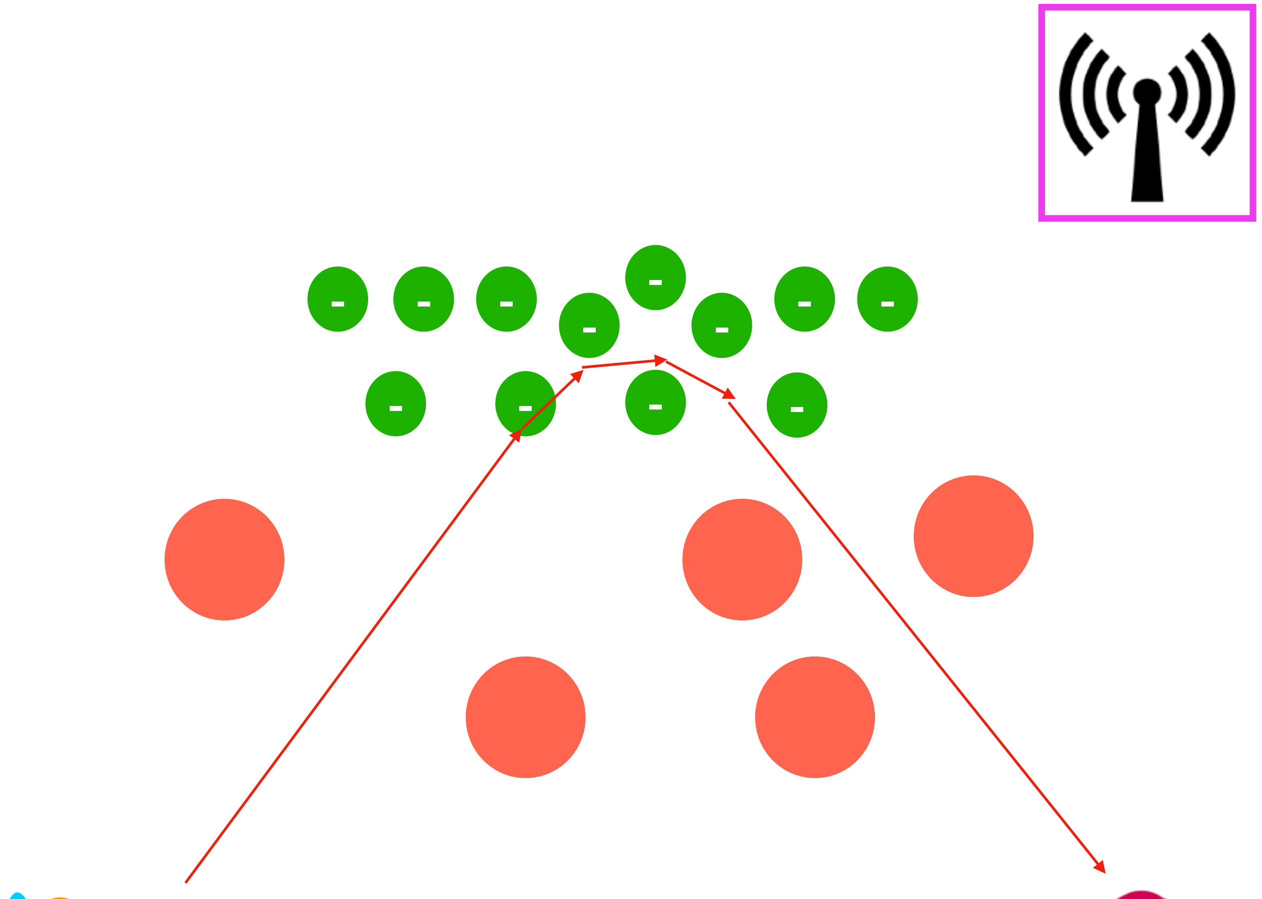
This is why the transition between the impacted area and the undisturbed area is abrupt: a ‘sharp’ transition area (plasmasheet - see next slide)
The solar energetic particles catch up with a magnetic field line of the earths magnetosphere and gyrate down towards the polar regions.
They mainly drop in in the area with open magnetic field lines (red).

Plasma sheet: area between open and closed magnetic fields

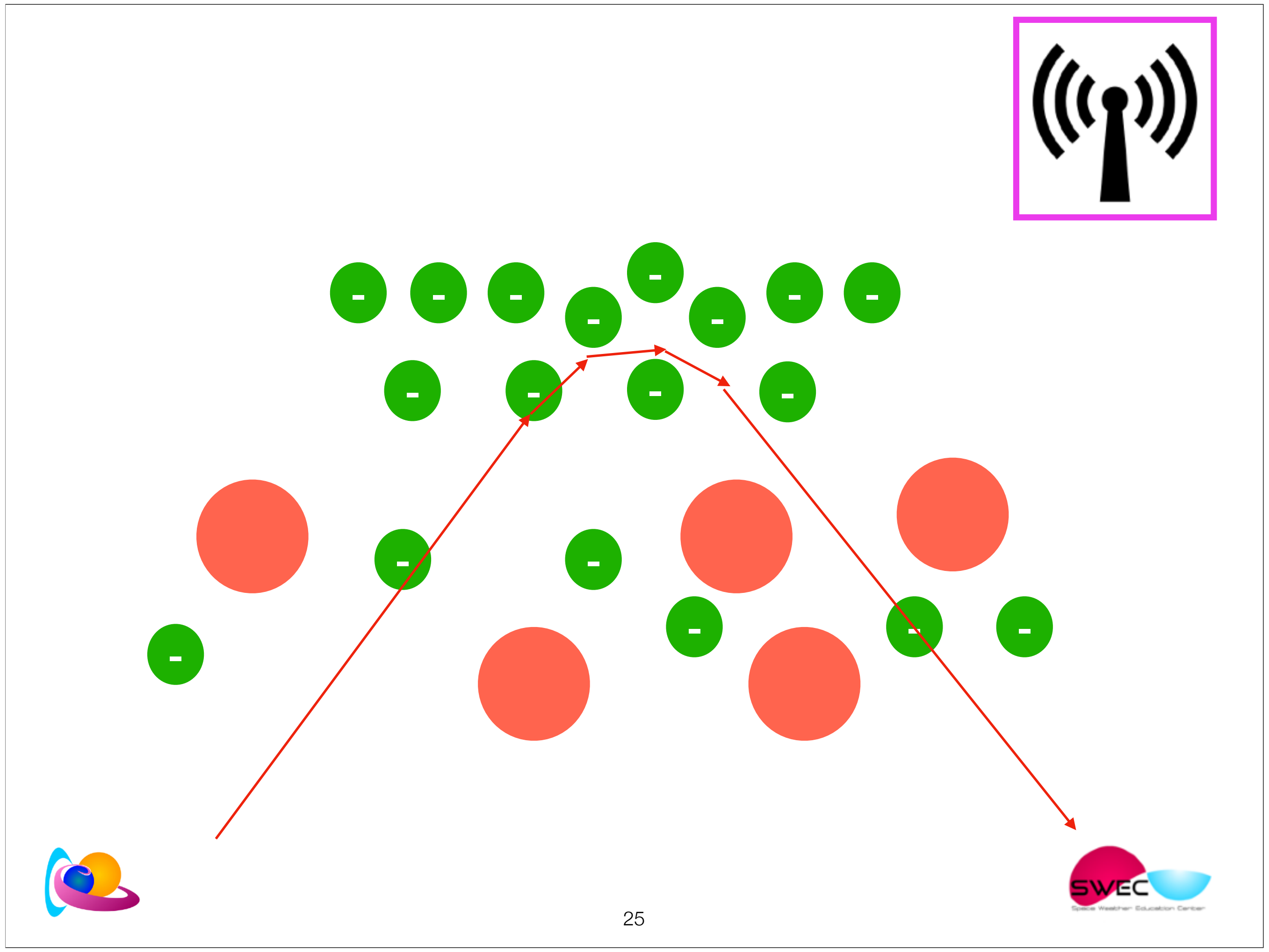


Radio wave makes the electrons move. Those moving electrons reproduce on their turn the radio signal and re-emitting it.

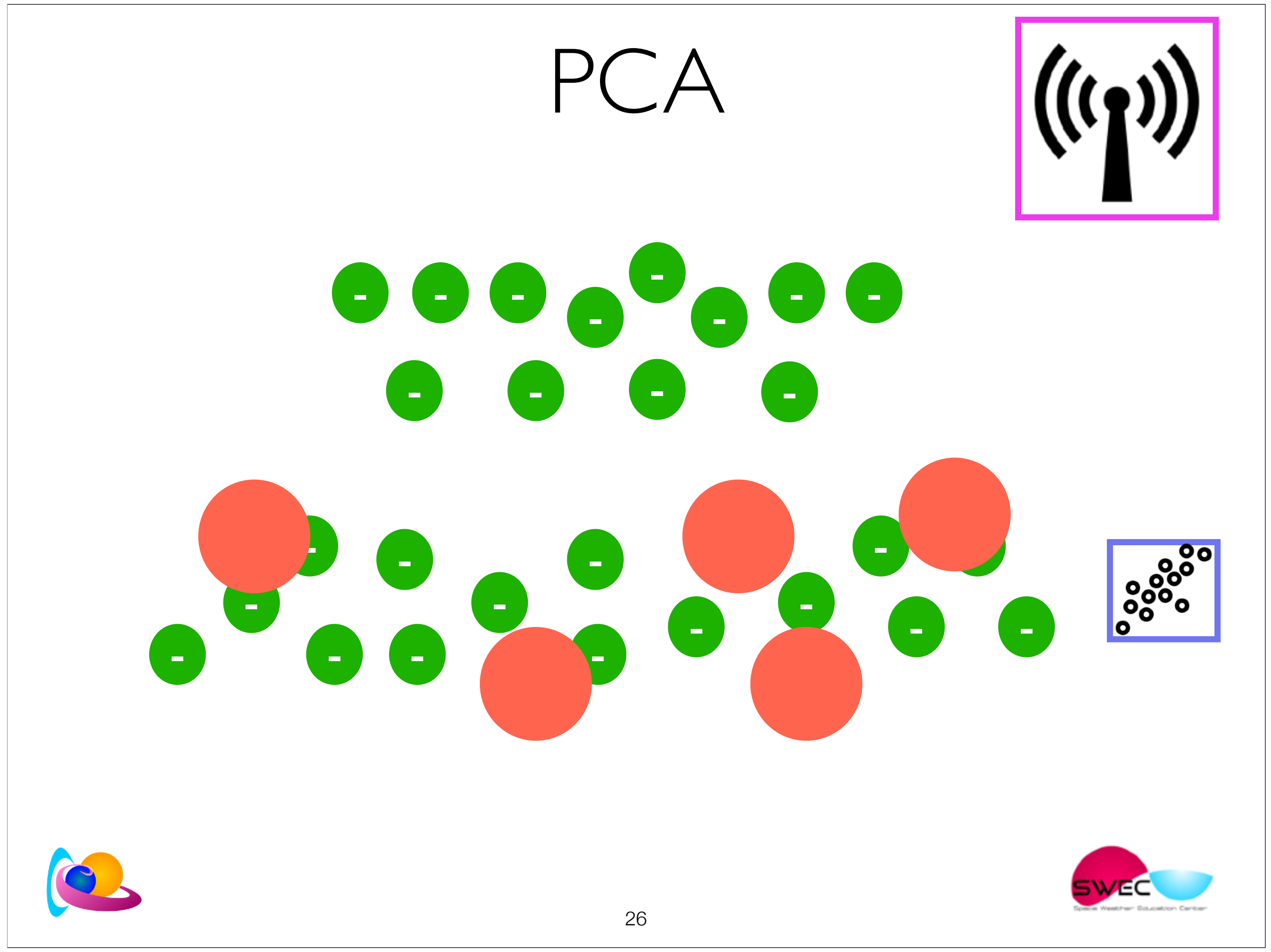
The ionosphere refracts radio waves
More refraction when higher the electron density or lower the frequency
When there are more electrons, the wave is more bent and again bent and again … until it is going down.
This is how reflection works in the ionosphere. It is a region full of magic (with a negative refractive index).



Neutrals are being present.
This is the D-layer during the night.



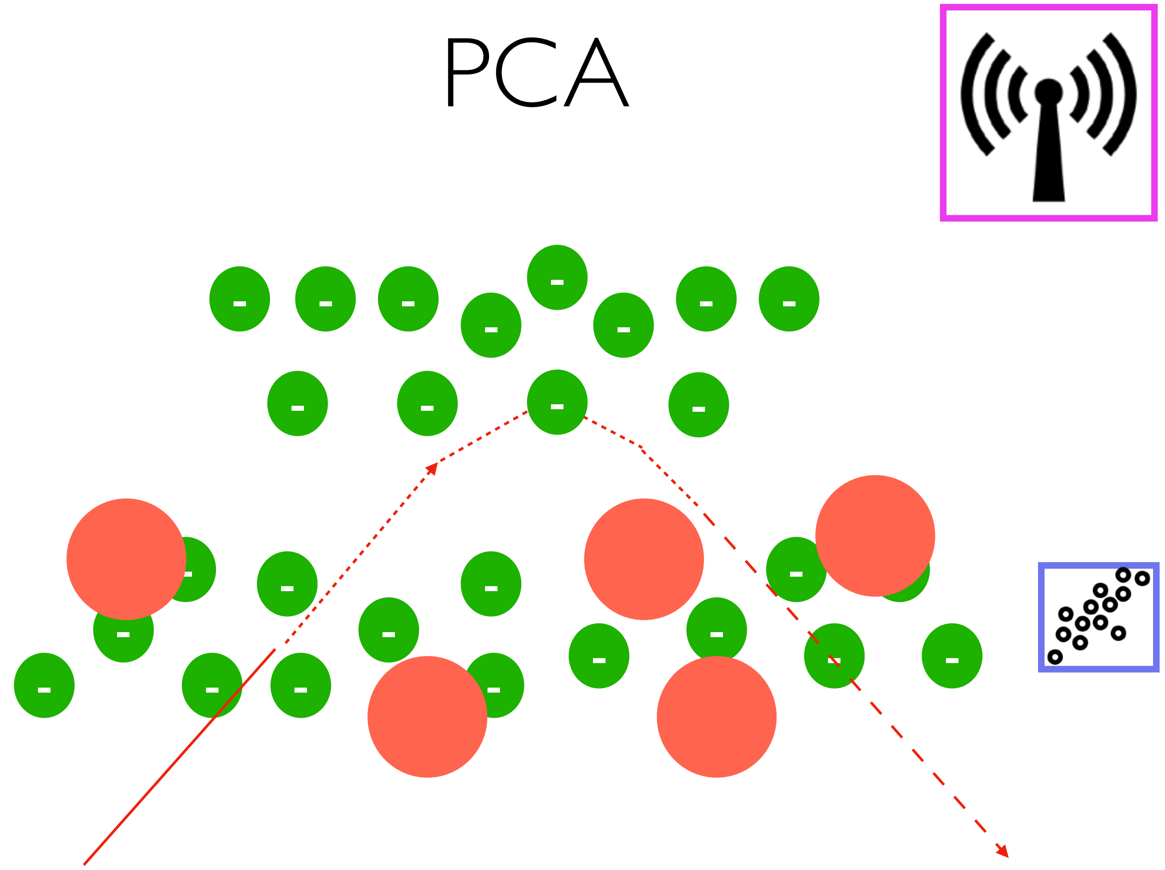
This is the D-layer during the day.
The radio wave also meets electrons in the D-layer. These electrons can’t move as much due to the neutral —> absorption.
Luckily, there are not many electrons and the absorption is minimal.



The incoming solar energetic particles ionise the D-layer.

The radio wave meets more electrons in the D-layer. During each encounter, the wave is being absorbed.

PCA



The radio wave meets more electrons in the D-layer. During each encounter, the wave is being absorbed.

April 23, 17:06 UT

```
SWX ADVISORY
DTG:               20230423/1706Z
SWXC:              PECASUS
ADVISORY NR:       2023/59
SWX EFFECT:        HF COM MOD
OBS SWX:           23/1655Z HNH W150 - E000
FCST SWX +6 HR:    23/2300Z NOT AVBL
FCST SWX +12 HR:   24/0500Z NOT AVBL
FCST SWX +18 HR:   24/1100Z NOT AVBL
FCST SWX +24 HR:   24/1700Z NOT AVBL
RMK:               SPACE WEATHER EVENT (HF COM POLAR CAP
ABSORPTION) IN PROGRESS. IMPACT ON LOWER HF COM FREQUENCY
BANDS EXPECTED AT HIGH LATITUDES.
NXT ADVISORY:      WILL BE ISSUED BY 20230423/2255Z=
```


Should have been: HNH + HSH W180-E180

April 23, 18:50 UT

10/10/2023
20:05 UTC

STATUS
ODC

- MAIN
- GNSS
- RADIATION
- HF COM
- ARCHIVE
- Advisory
- Daily Brief
- Data
- Procedures
- Portfolio
- ICAO Docs
- RWC
- Contact
- Mute status
- OnCall Report

-24h -12h -6h -3h -1h -5m Submit 2023-04-23 18:50 now +5m +1h +3h +6h +12h +24h

PECASUS DASHBOARD on 2023-04-23 18:50 UTC

GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2023-04-23 18:50	0.40	QUIET		0.40	QUIET
Phase Scintillation	0.4	0.7	2023-04-23 18:50	0.26	QUIET		0.26	QUIET
Vertical TEC	125	175	2023-04-23 18:50	124.06	QUIET		124.06	QUIET

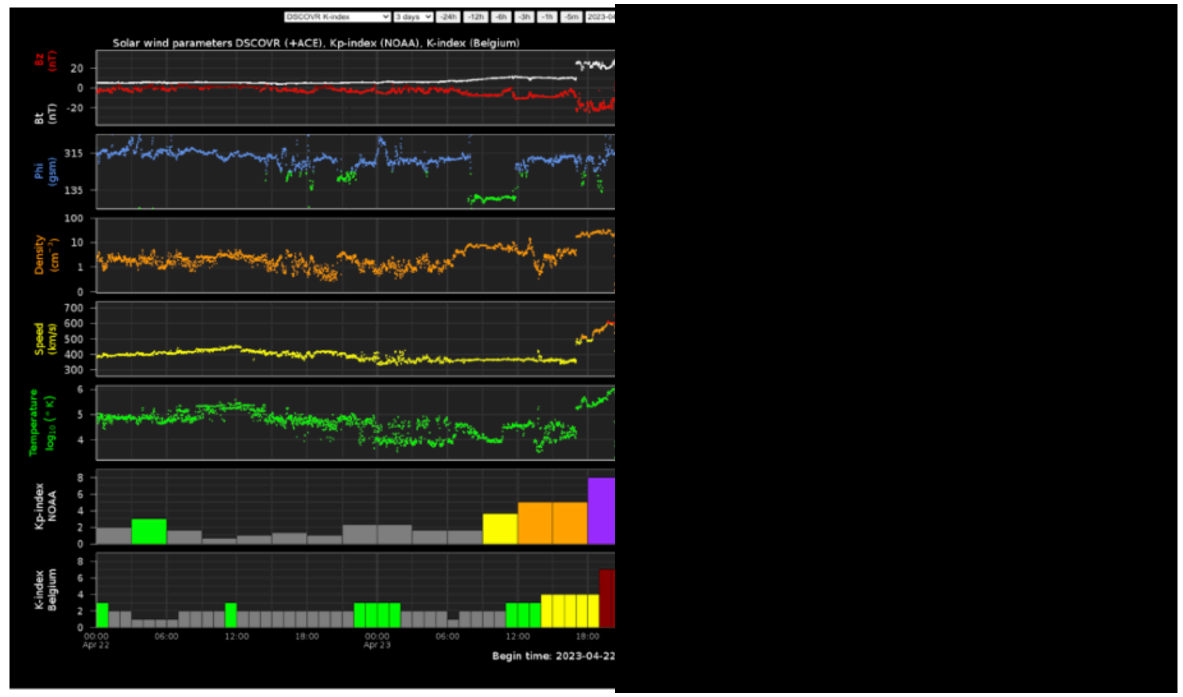
RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL ≤ 460	30	80	2023-04-23 18:50	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2023-04-23 18:50	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2023-04-23 18:50	8.0	MODERATE		8.0	MODERATE
Polar Cap Absorption (PCA)	2	5	2023-04-23 18:50	3.13	MODERATE		4.64	MODERATE
Shortwave Fadeout (SWF)	x1.0	x10.0	2023-04-23 18:50	< M5 flare	QUIET		< M5 flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2023-04-23 18:00	2	SEVERE		2	SEVERE

Sound alarm is triggered when MOD or SEV thresholds are exceeded or in case of data outages.

>1 hour later, it began
Passed Kp 6, leading to PSD but first focus on AA

CME arrival

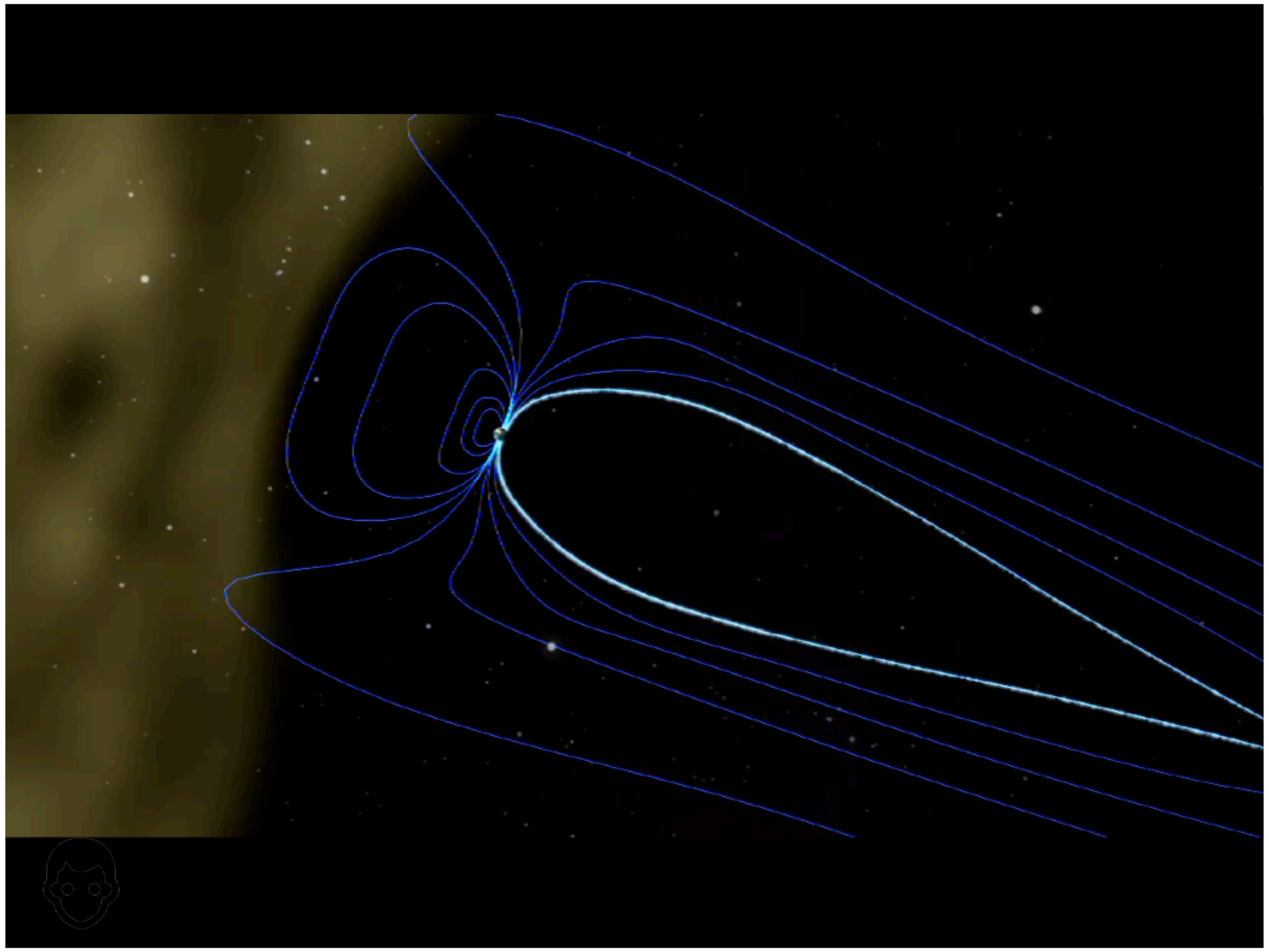


Geomagnetic Storm because of a CME arrival!

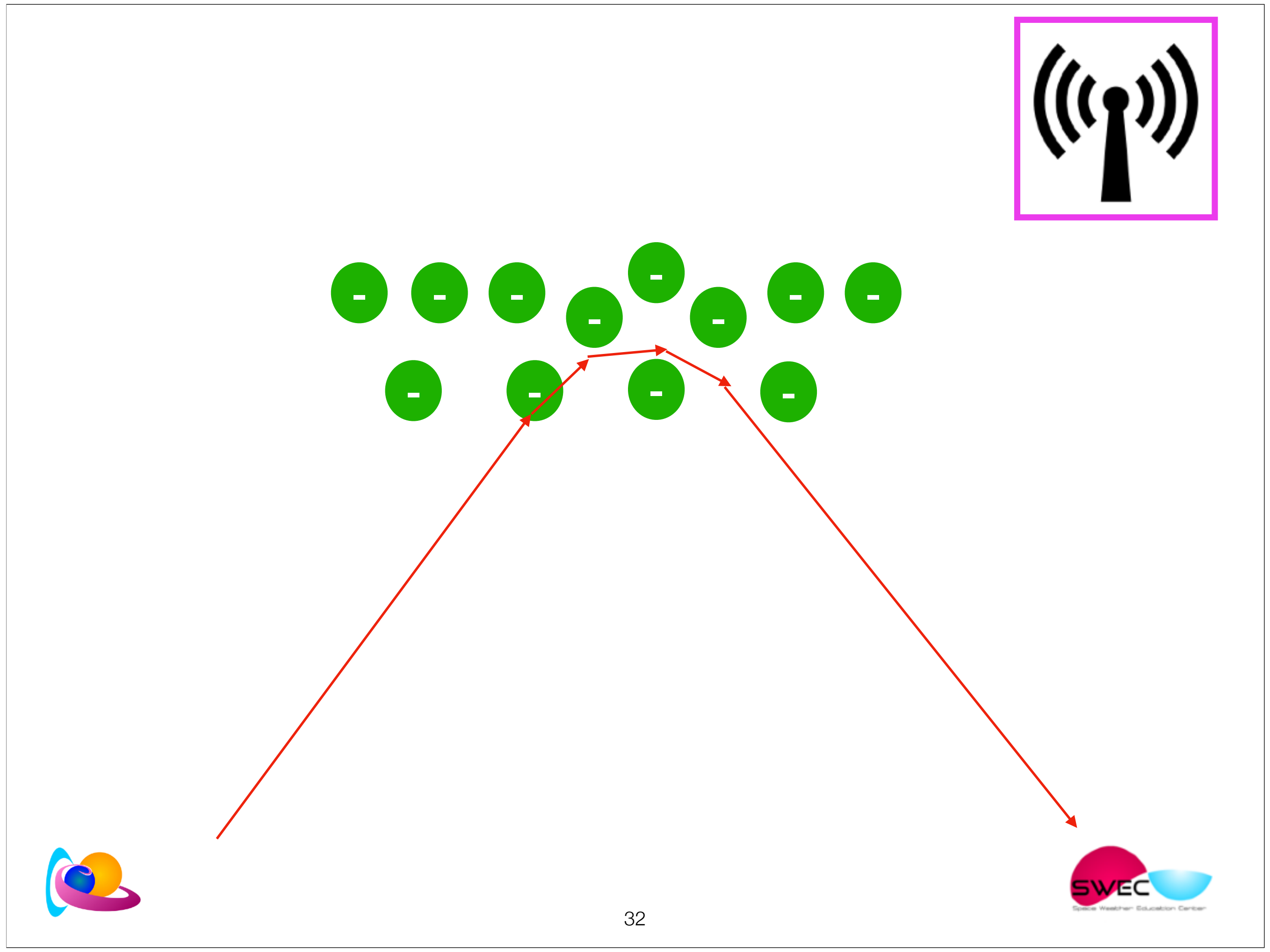
The cloud induced a **severe geomagnetic storm on the planetary level** (purple rectangles in the 6th panel)) and a **moderate geomagnetic storm locally** in Belgium (dark red rectangles in the 7th panel).

These graphs show (from top to bottom): the outward component of the magnetic field, the total magnetic field, the direction of the magnetic field, the density of the solar wind, the velocity of the solar wind, the temperature of the solar wind, The planetary K-index and the Local K-index for Belgium.

Solar wind speed jumped from 360 to 475 km/s, then gradually further increased to values near 700 km/s by 21:00UTC. Bz, the north-south component of the interplanetary magnetic field, showed 2 prolonged periods of negative values: during the 17-20UTC interval, when its value was at a fairly stable -24 nT, and again on 24 April during the 01-09UTC interval when Bz evolved from -33 nT to -9 nT. The Bz value of -33 nT was the lowest since the 7 September 2017 storm (also -33 nT). For even more negative Bz, we have to go back all the way to the Solstice storm of 22 June 2015 when it reached values of -39 nT.

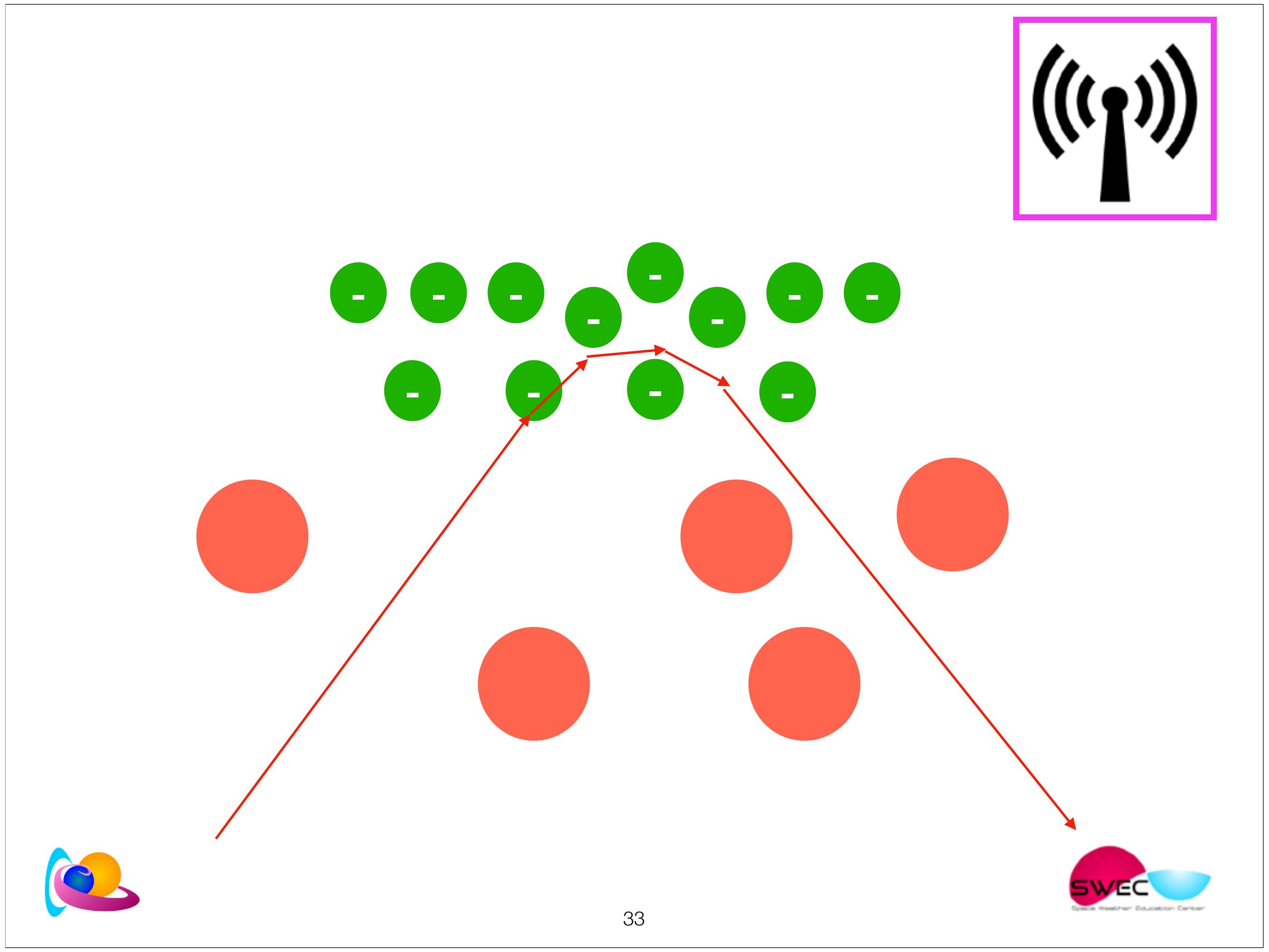


Precipitating electrons coming from the tail

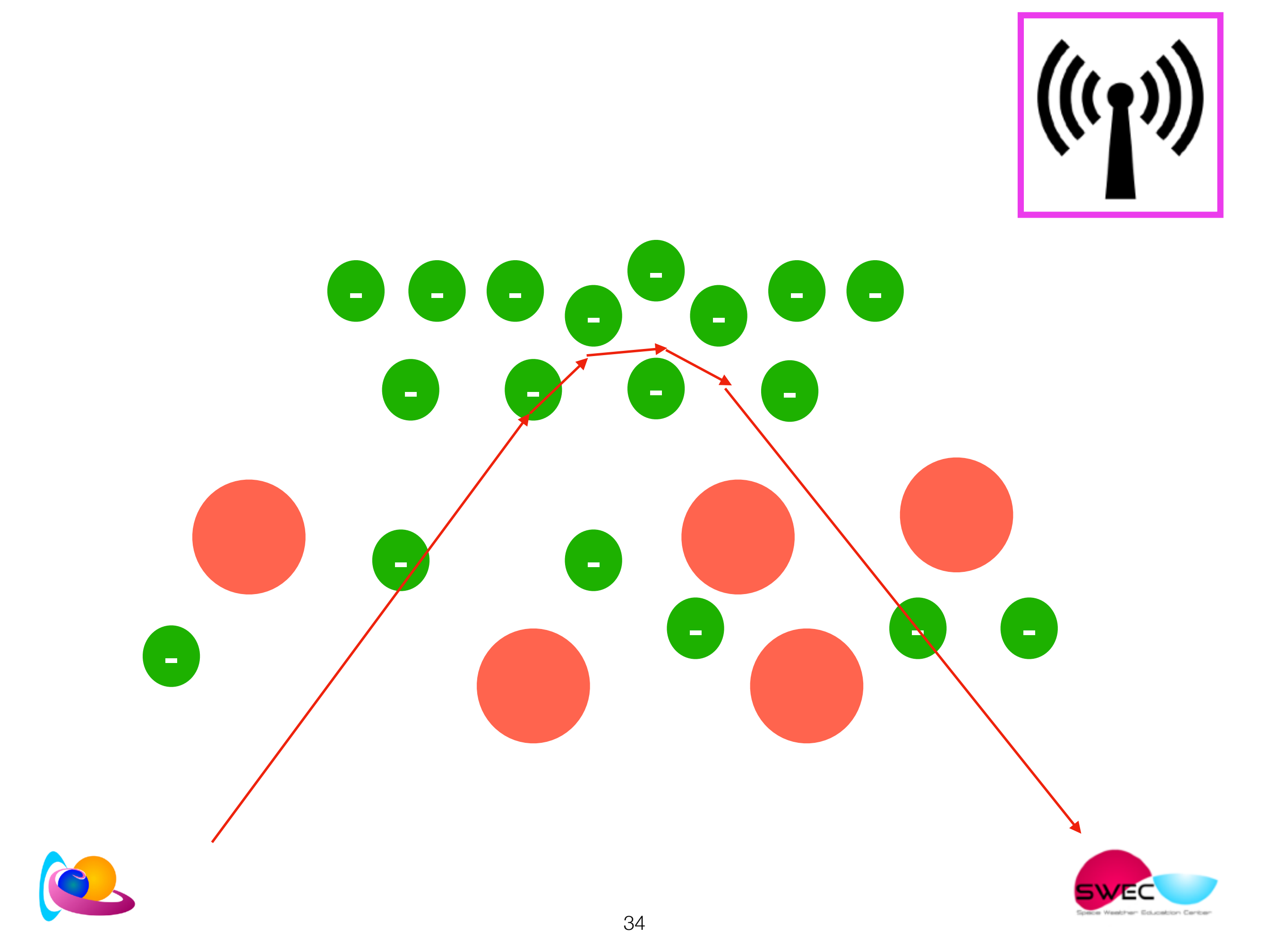


Radio wave makes the electrons move. Those moving electrons reproduce on their turn the radio signal and re-emitting it.

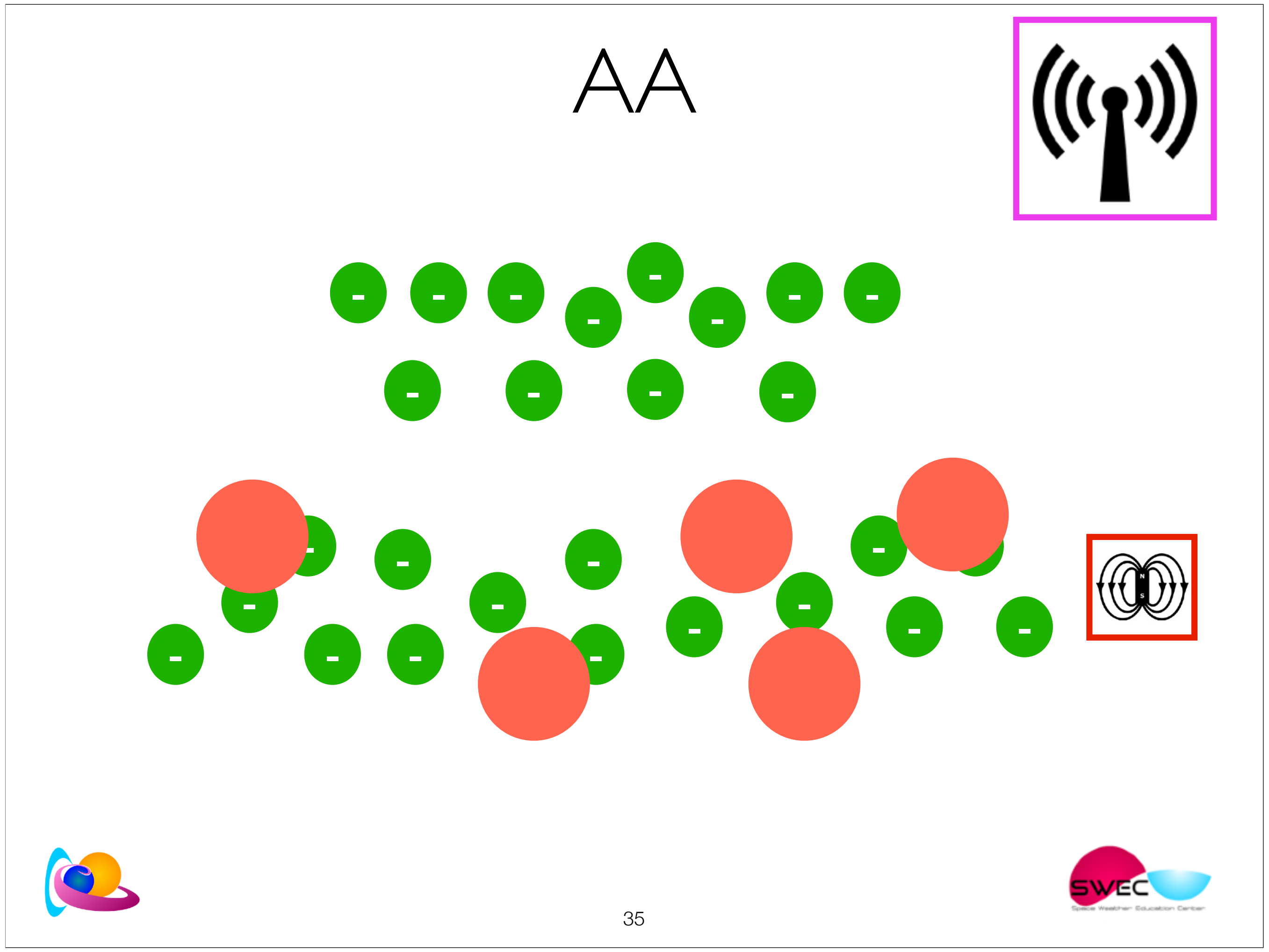
The ionosphere refracts radio waves
More refraction when higher the electron density or lower the frequency
When there are more electrons, the wave is more bent and again bent and again … until it is going down.
This is how reflection works in the ionosphere. It is a region full of magic (with a negative refractive index).



Neutrals are being present.

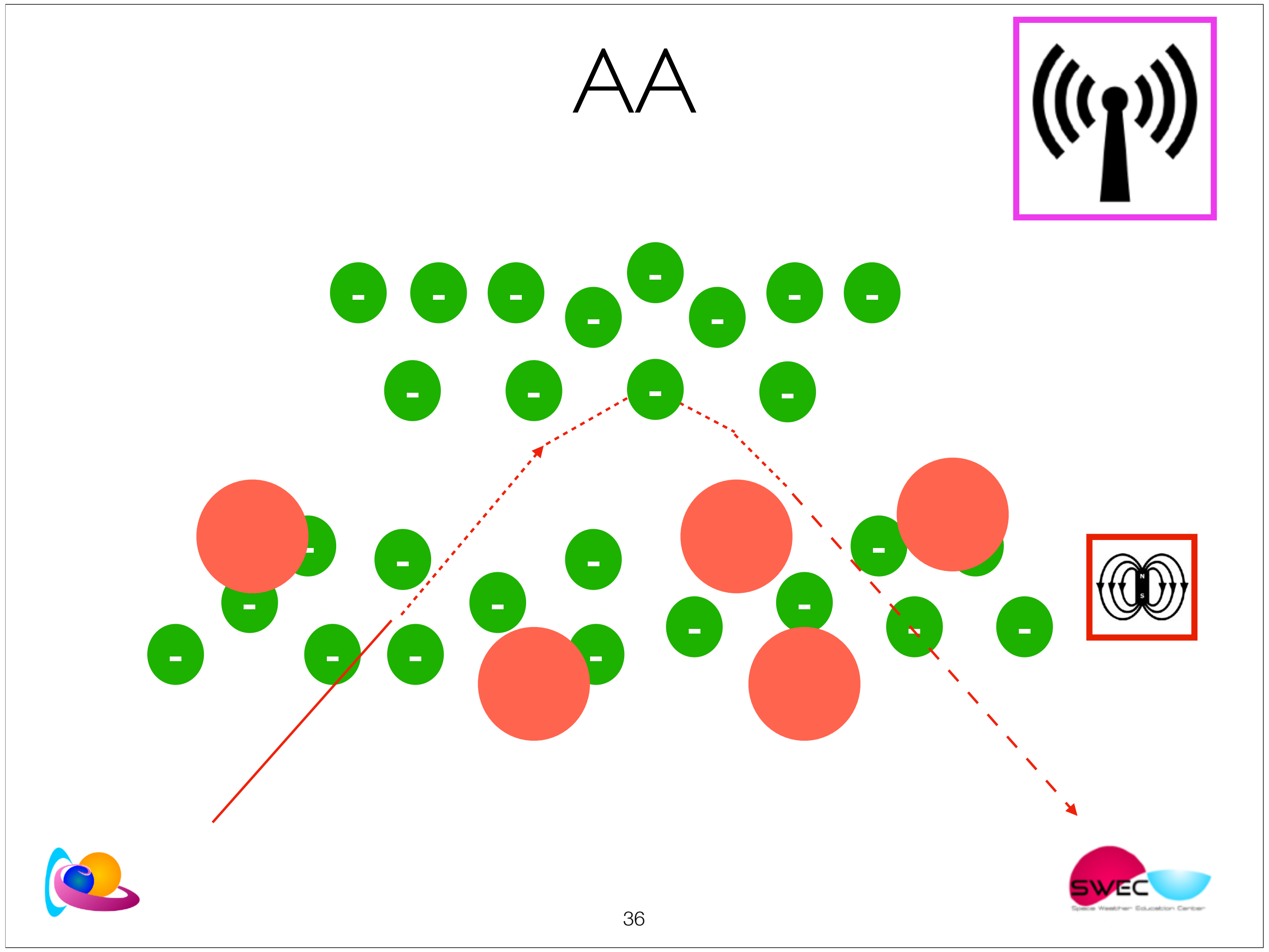


The radio wave also meets electrons in the D-layer. These electrons can’t move as much due to the neutral —> absorption. Luckily, there are not many electrons and the absorption is minimal.



The incoming solar energetic particles ionise the D-layer.

The radio wave meets more electrons in the D-layer. During each encounter, the wave is being absorbed.



The radio wave meets more electrons in the D-layer. During each encounter, the wave is being absorbed.

April 23, 19:57 UT

```
SWX ADVISORY
DTG:               20230423/1957Z
SWXC:              PECASUS
ADVISORY NR:       2023/61
NR RPLC:           2023/60
SWX EFFECT:        HF COM MOD
OBS SWX:           23/1950Z HNH HSH W180 - E180
FCST SWX +6 HR:    24/0200Z NOT AVBL
FCST SWX +12 HR:   24/0800Z NOT AVBL
FCST SWX +18 HR:   24/1400Z NOT AVBL
FCST SWX +24 HR:   24/2000Z NOT AVBL
RMK:               SPACE WEATHER EVENT (HF COM AURORAL
ABSORPTION) IN PROGRESS. IMPACT ON LOWER HF COM FREQUENCY
BANDS EXPECTED AT HIGH LATITUDES.
NXT ADVISORY:      WILL BE ISSUED BY 20230424/0150Z=
```

-24h -12h -6h -3h -1h -5m Submit 2023-04-23 18:50 now +5m +1h +3h +6h +12h +24h

10/10/2023
20:05 UTC

STATUS
ODC

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Mute status
OnCall Report

PECASUS DASHBOARD on 2023-04-23 18:50 UTC

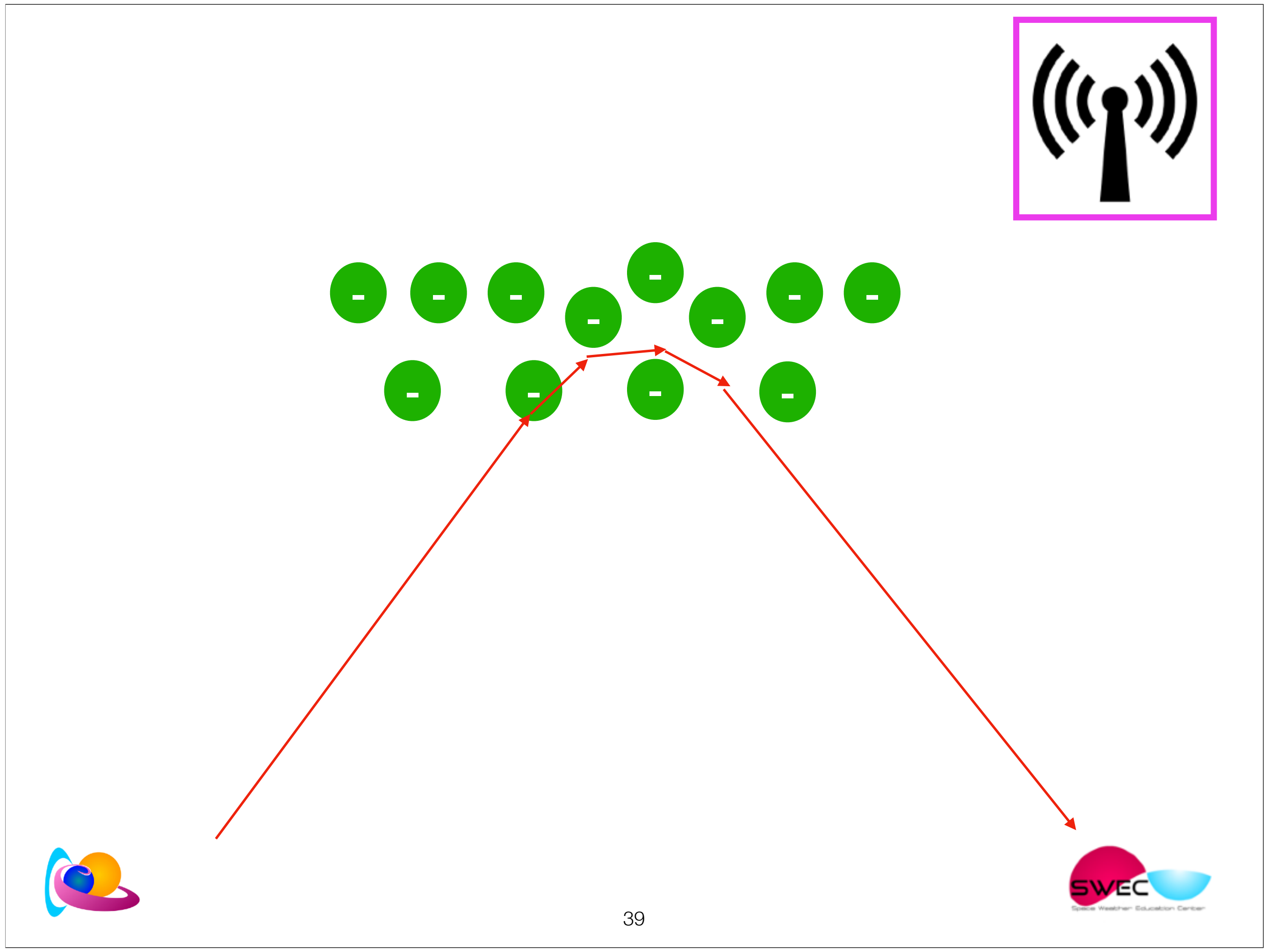
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2023-04-23 18:50	0.40	QUIET		0.40	QUIET
Phase Scintillation	0.4	0.7	2023-04-23 18:50	0.26	QUIET		0.26	QUIET
Vertical TEC	125	175	2023-04-23 18:50	124.06	QUIET		124.06	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL ≤ 460	30	80	2023-04-23 18:50	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2023-04-23 18:50	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2023-04-23 18:50	8.0	MODERATE		8.0	MODERATE
Polar Cap Absorption (PCA)	2	5	2023-04-23 18:50	3.13	MODERATE		4.64	MODERATE
Shortwave Fadeout (SWF)	x1.0	x10.0	2023-04-23 18:50	< M5 flare	QUIET		< M5 flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2023-04-23 18:00	2	SEVERE		2	SEVERE

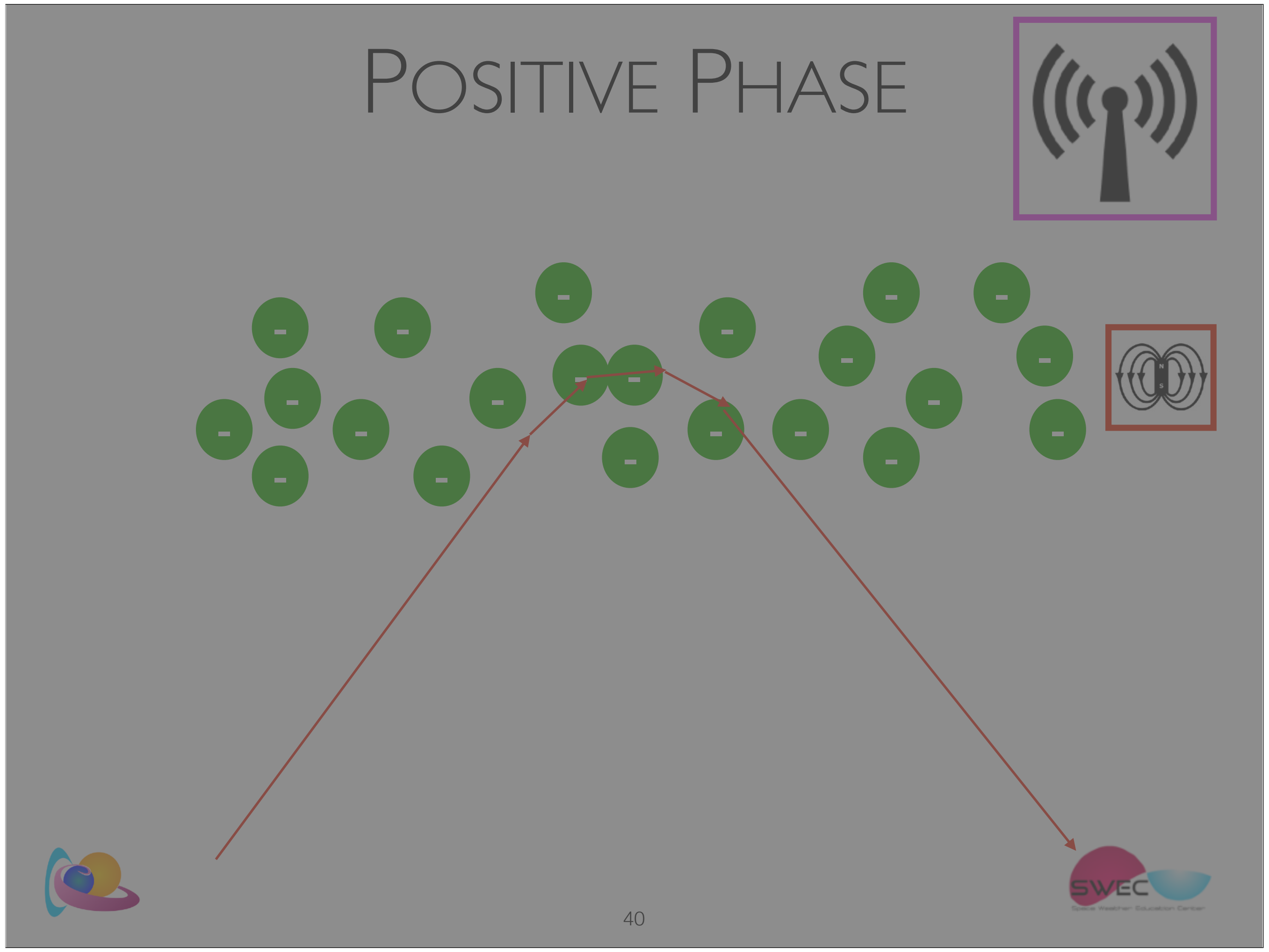
Sound alarm is triggered when MOD or SEV thresholds are exceeded or in case of data outages.

Focus on Post Storm Depression



The ionosphere can reflect waves

When the ionosphere is not ionised, which waves are being reflected?
As soon as the ionisation increases, waves under the MUF are being reflected.
The higher the ionisation, the higher the MUF.



Increase of electrons - positive phase of the storm - VTEC increases

increase is due to Drift of plasma across B = upward flow

Better HF communication because more waves are being reflected.

Also waves with a higher freq are being reflected. MUF increases

The most significant disturbances to the ionosphere result from solar events (CMEs, CIRs), propagating through the solar wind and interacting with the magnetosphere.

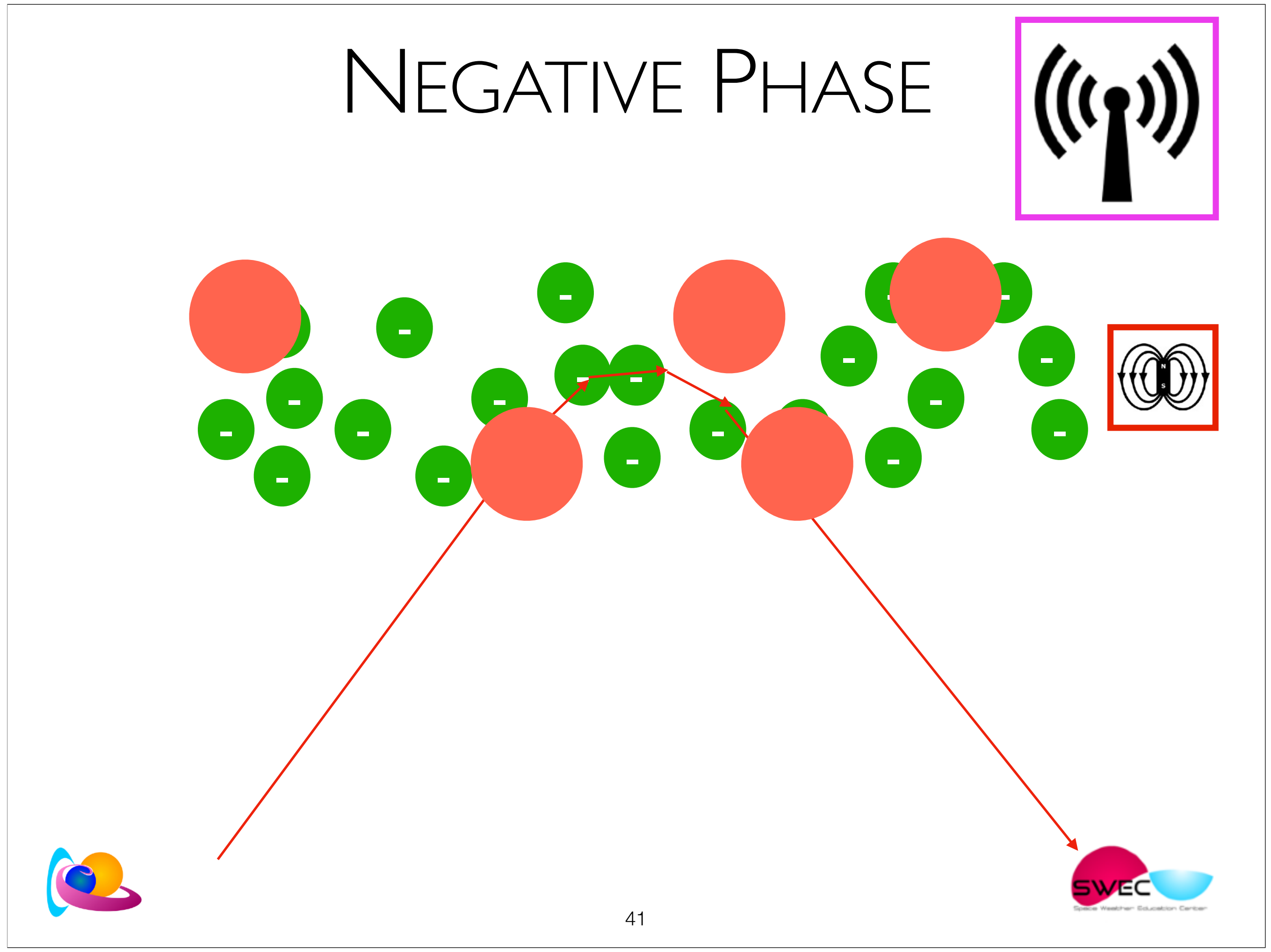
1 Energy injected into the ionosphere, mainly at high latitude.

2 As a result, the auroral oval expands in height and width

3 This causes large scale movement of plasma towards the equator.

4 Drift along the magnetic field lines cause the ionosphere to move up, which can increase electron density ("positive storm phase").

5 Finally, upwelling of N2 causes increased recombination, leading to a depletion of ionisation ("negative storm phase").



Increase of electrons - positive phase of the storm - VTEC increases
increase is due to Drift of plasma across B = upward flow
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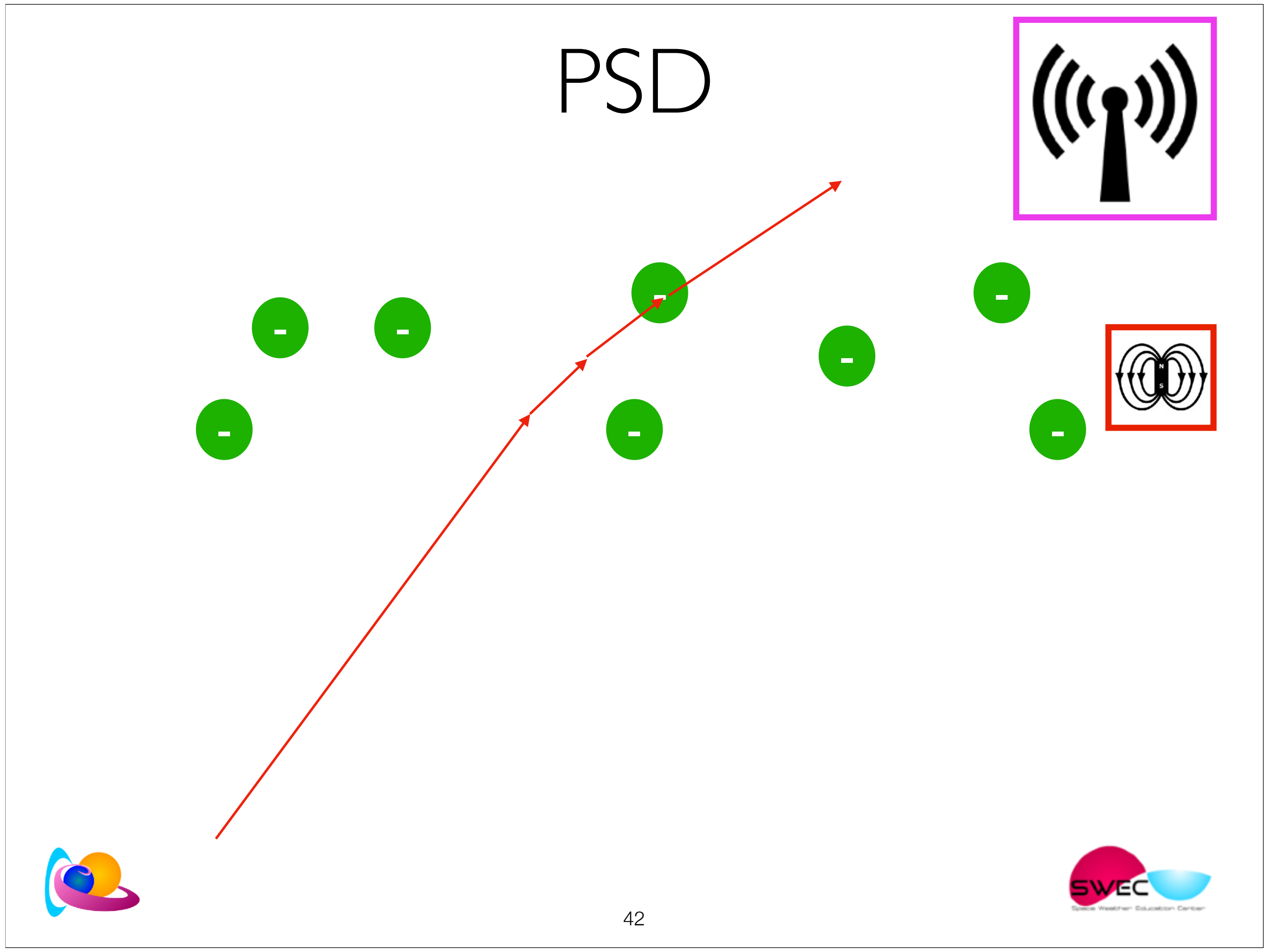

Neutrals are being transported to the F2 layer. This is the second, negative phase of the storm - more electron are being eaten by neutrals.
Less electrons, the MUF decreases —> less frequencies available for HF com
Higher freq radio waves pass through
<u>—> mid-latitude</u>

The most significant disturbances to the ionosphere result from solar events (CMEs, CIRs), propagating through the solar wind and interacting with the magnetosphere.

1 Energy injected into the ionosphere, mainly at high latitude.
2 As a result, the auroral oval expands.
3 This causes large scale movement of plasma towards the equator.
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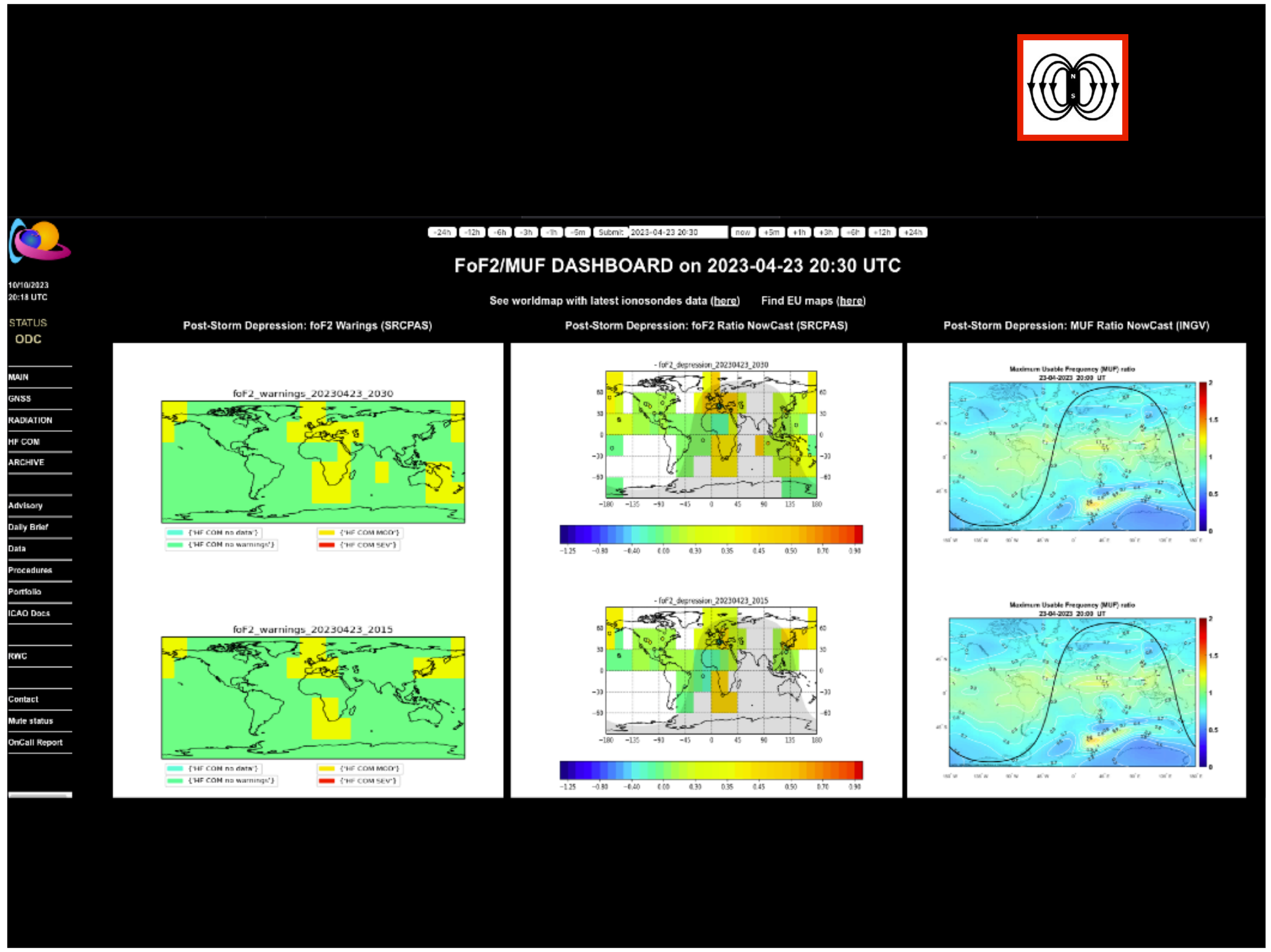

Areas of PSD —> where there are stations.

April 23, 20:29 UT

```
FNXX02 EFKL 232029

SWX ADVISORY
DTG:               20230423/2029Z
SWXC:              PECASUS
ADVISORY NR:       2023/62
SWX EFFECT:        HF COM MOD
OBS SWX:           23/2021Z EQS MSH E000 – E045
FCST SWX +6 HR:    24/0300Z NOT AVBL
FCST SWX +12 HR:   24/0900Z NOT AVBL
FCST SWX +18 HR:   24/1500Z NOT AVBL
FCST SWX +24 HR:   24/2100Z NOT AVBL
RMK:               SPACE WEATHER EVENT (MAXIMUM USABLE
FREQUENCY DEPRESSION) IS IN PROGRESS. IMPACT ON HIGHER HF
COM FREQUENCY BANDS EXPECTED.
NXT ADVISORY:      WILL BE ISSUED BY 20230424/0221Z=
```

April 23, 20:36 UT

-24h -12h -6h -3h -1h -5m Submit 2023-04-23 20:36 now +5m +1h +3h +6h +12h +24h

10/10/2023
20:34 UTC

STATUS
ODC

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HF COM
ARCHIVE

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Portfolio
ICAO Docs

RWC

Contact
Mute status

PECASUS DASHBOARD on 2023-04-23 20:36 UTC

GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2023-04-23 20:36	1.08	SEVERE		1.08	SEVER
Phase Scintillation	0.4	0.7	2023-04-23 20:36	0.30	QUIET		1.06	SEVER
Vertical TEC	125	175	2023-04-23 20:35	131.84	QUIET		134.83	MODERATE

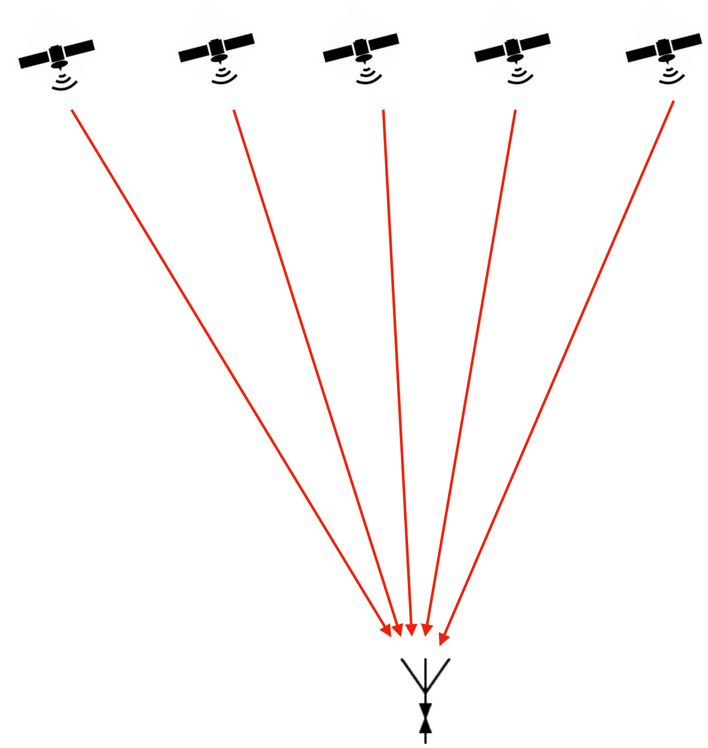
RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL ≤ 460	30	80	2023-04-23 20:35	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2023-04-23 20:35	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2023-04-23 20:36	8.0	MODERATE		8.0	MODERATE
Polar Cap Absorption (PCA)	2	5	2023-04-23 20:35	1.97	QUIET		4.64	MODERATE
Shortwave Fadeout (SWF)	x1.0	x10.0	2023-04-23 20:36	< M5 flare	QUIET		< M5 flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2023-04-23 20:00	2	SEVERE		2	SEVERE

Sound alarm is triggered when MOD or SEV thresholds are exceeded or in case of data outages.

New telephone call
focus on AS

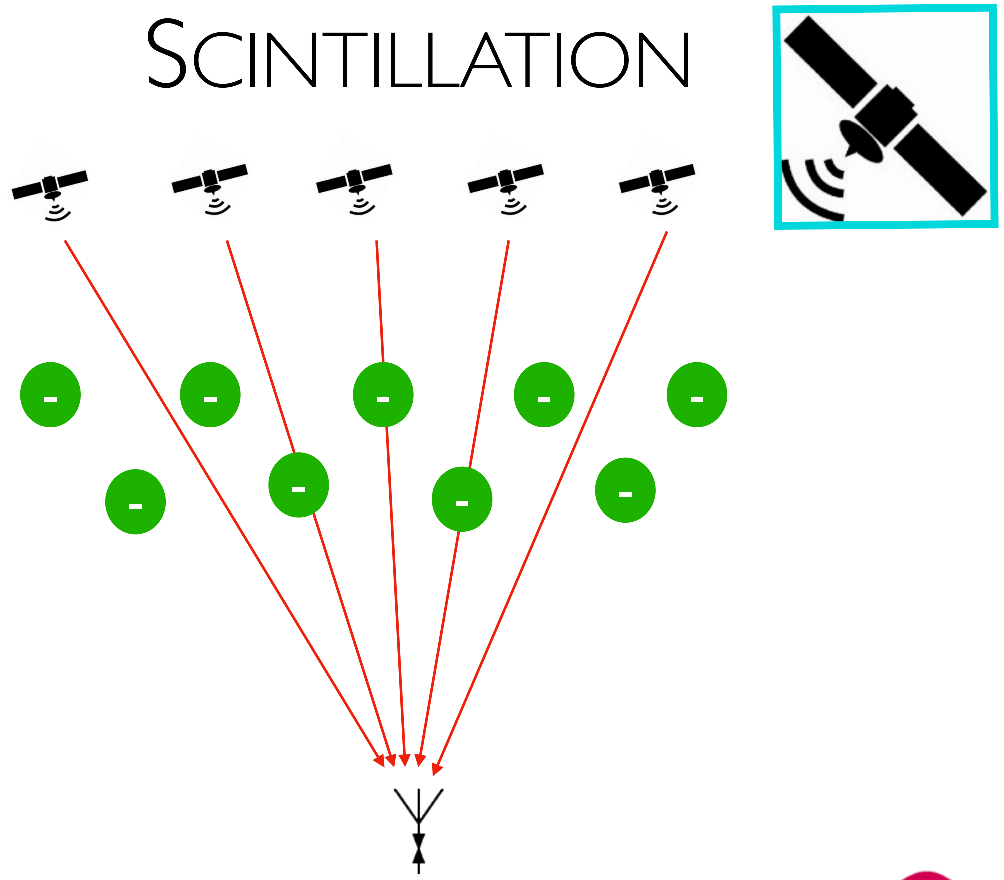
SCINTILLATION



no ionosphere - or an ionosphere that behaves as expected

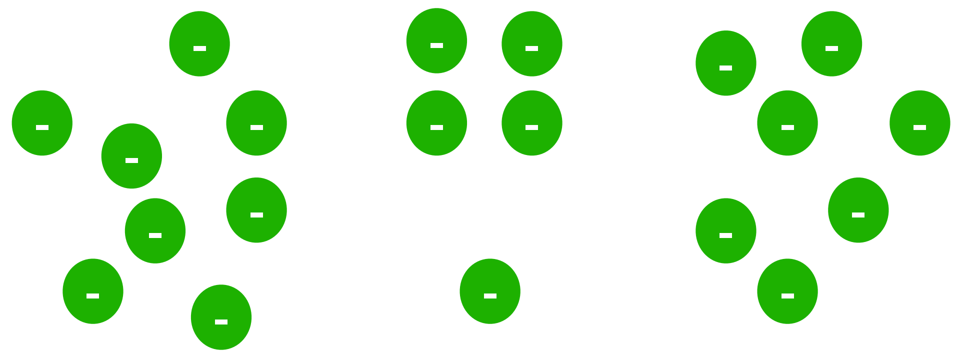
No refraction
No diffraction
The waves nicely reach the receiver without meeting another wave.

SCINTILLATION



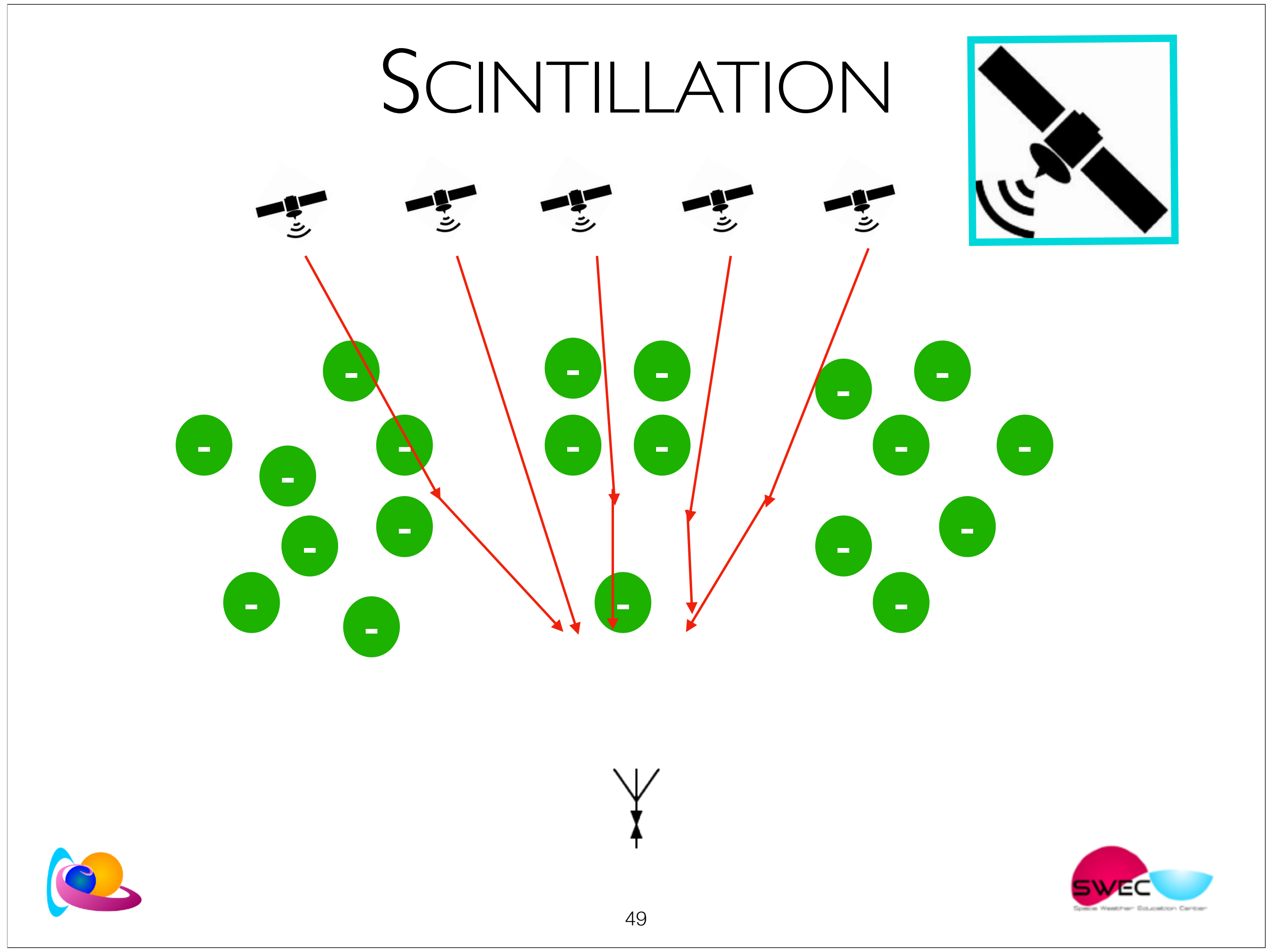
Even with an ionosphere that behaves, it is OK.

SCINTILLATION



Due to space weather, small scale irregularities exist in the ionosphere.
Landscape of electrons - dense regions and less dense regions
Localised
Due to

- Post-sunset Plasma Bubbles at lower latitudes
- Precipitating particles in the auroral oval
- Patches in the polar caps
- Travelling ionospheric disturbances

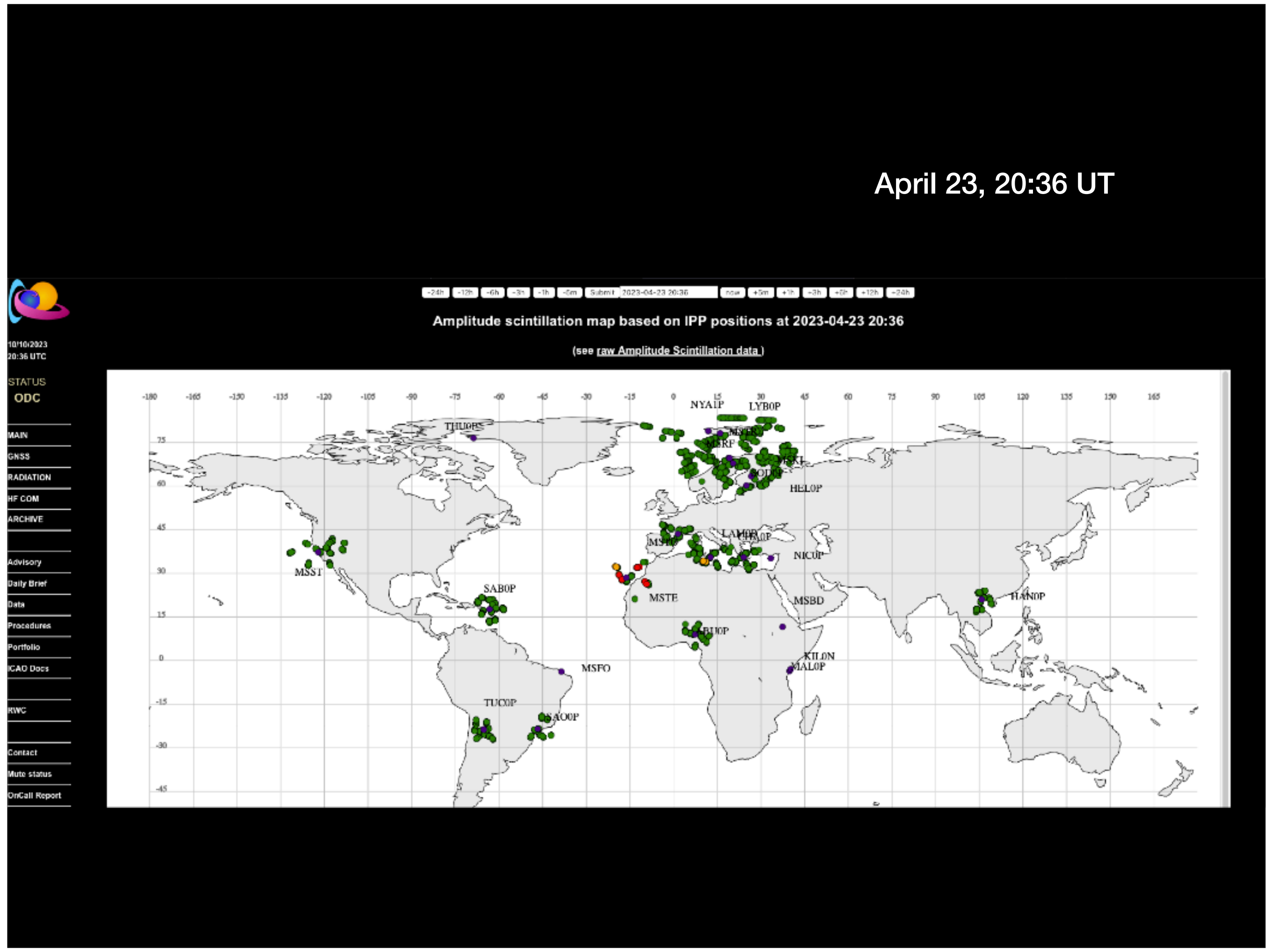


Due to space weather, small scale irregularities exist in the ionosphere.
Landscape of electrons - dense regions and less dense regions
Localised
REFRACTION
When a wave enters another medium, its speed is different. The wave is redirected as it passes from one medium to another —> delay
DIFFRACTION
A wave bends around the corner of an obstacle.
—> refracted and diffracted waves interfere —> As a result, the receiver sees a twinkling signal, i.e. the signal with rapid variations superimposed on it.

Regions of scintillation:

- Polar caps — solar energetic particles
- Auroral oval - trapped particles from the plasma sheet
- Equatorial region - equatorial ionisation anomaly - plasma bubbles - Rayleigh Taylor instability

The result is the same, the cause of the density irregularity is different.



The four mechanisms that give rise to scintillation are

- Plasma bubbles (in the lower latitudes)
- Precipitating particles (auroral oval)
- Patches in the polar caps
- Travelling ionospheric disturbances

All three happen more or less depending on the circumstances, but plasma bubbles happen most of the days.

April 23, 20:36 UT

Link between a station and satellites
A cross is one minute.

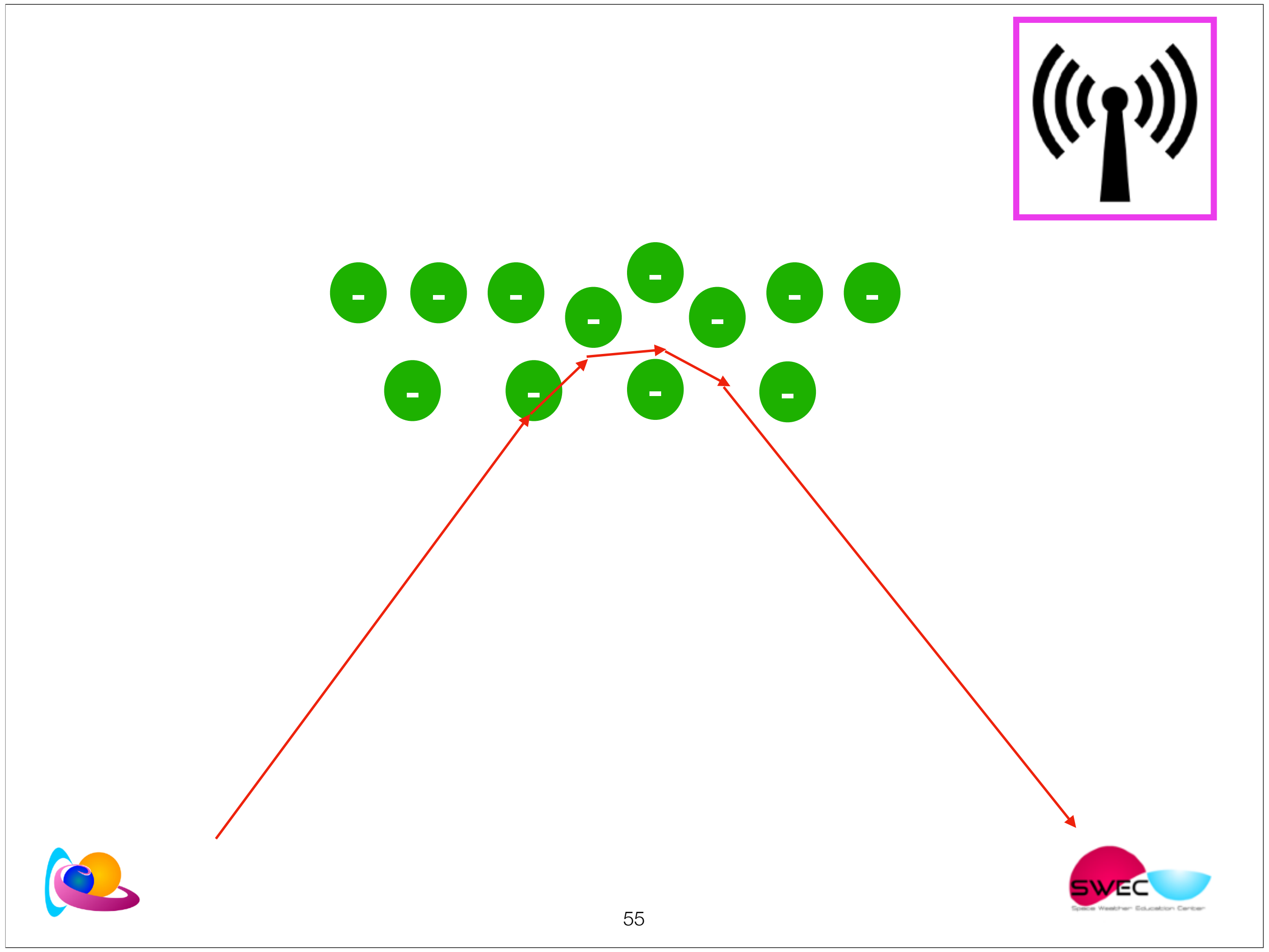
April 23, 20:36 UT

```
SWX ADVISORY
DTG:              20230423/2036Z
SWXC:             PECASUS
ADVISORY NR:      2023/141
SWX EFFECT:       GNSS SEV
OBS SWX:          23/2029Z EQN W030 – E000
FCST SWX +6 HR:   24/0300Z NOT AVBL
FCST SWX +12 HR:  24/0900Z NOT AVBL
FCST SWX +18 HR:  24/1500Z NOT AVBL
FCST SWX +24 HR:  24/2100Z NOT AVBL
RMK:              SPACE WEATHER EVENT (IONOSPHERIC
DISTURBANCE) IN PROGRESS. IMPACT ON GNSS PERFORMANCE
POSSIBLY LEADING TO LOSS OF GNSS SIGNALS AND/OR DEGRADATION
 OF TIMING AND POSITIONING PERFORMANCE.
NXT ADVISORY:     WILL BE ISSUED BY 20230424/0229Z=
```

You made it until the end of this presentation!
Well done.

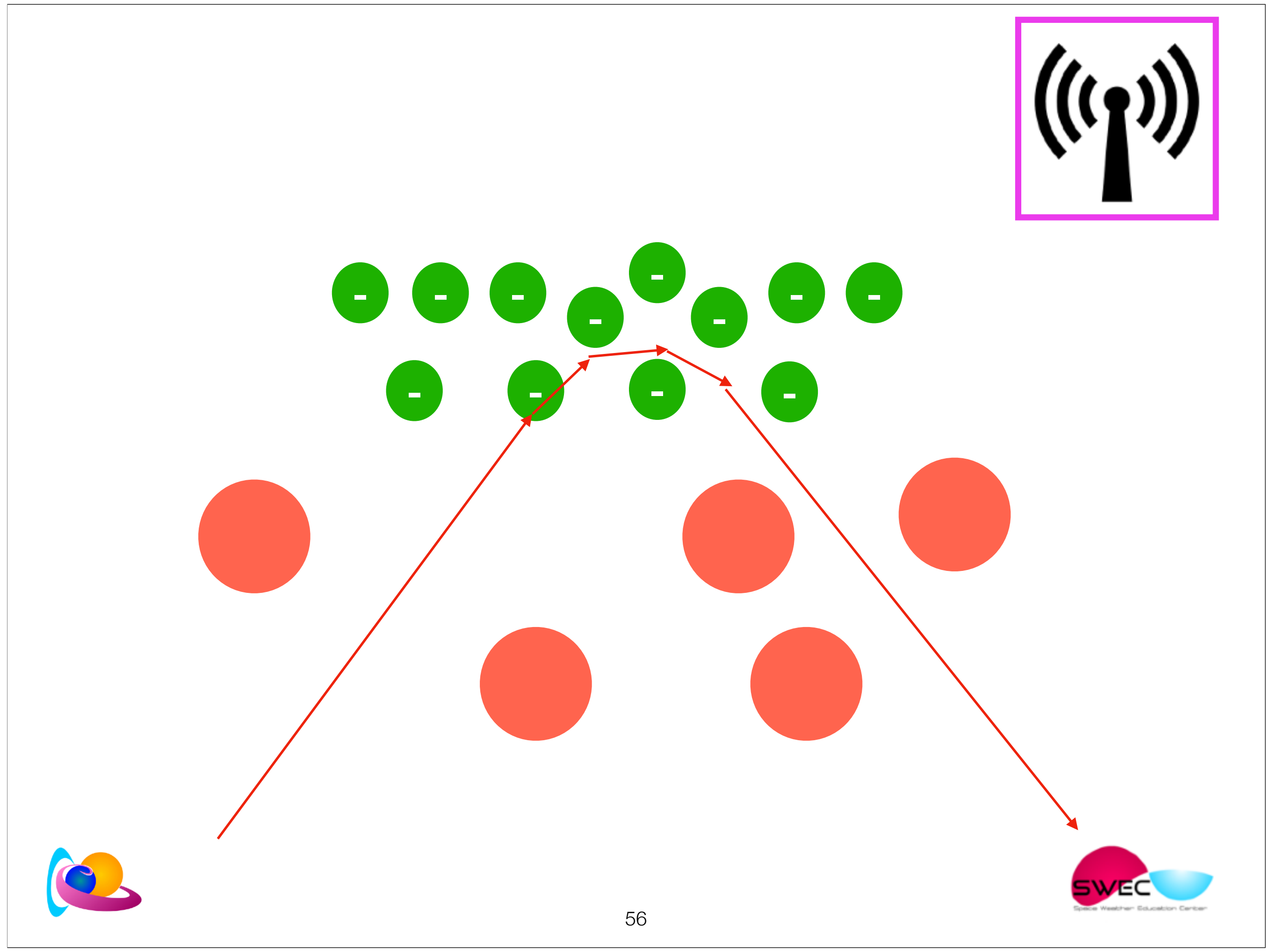
The PECASUS operator on duty at that time was not done yet. Trouble in the ionosphere continues until 4 days after Kp=6

Bis-slides:
What about SWF?

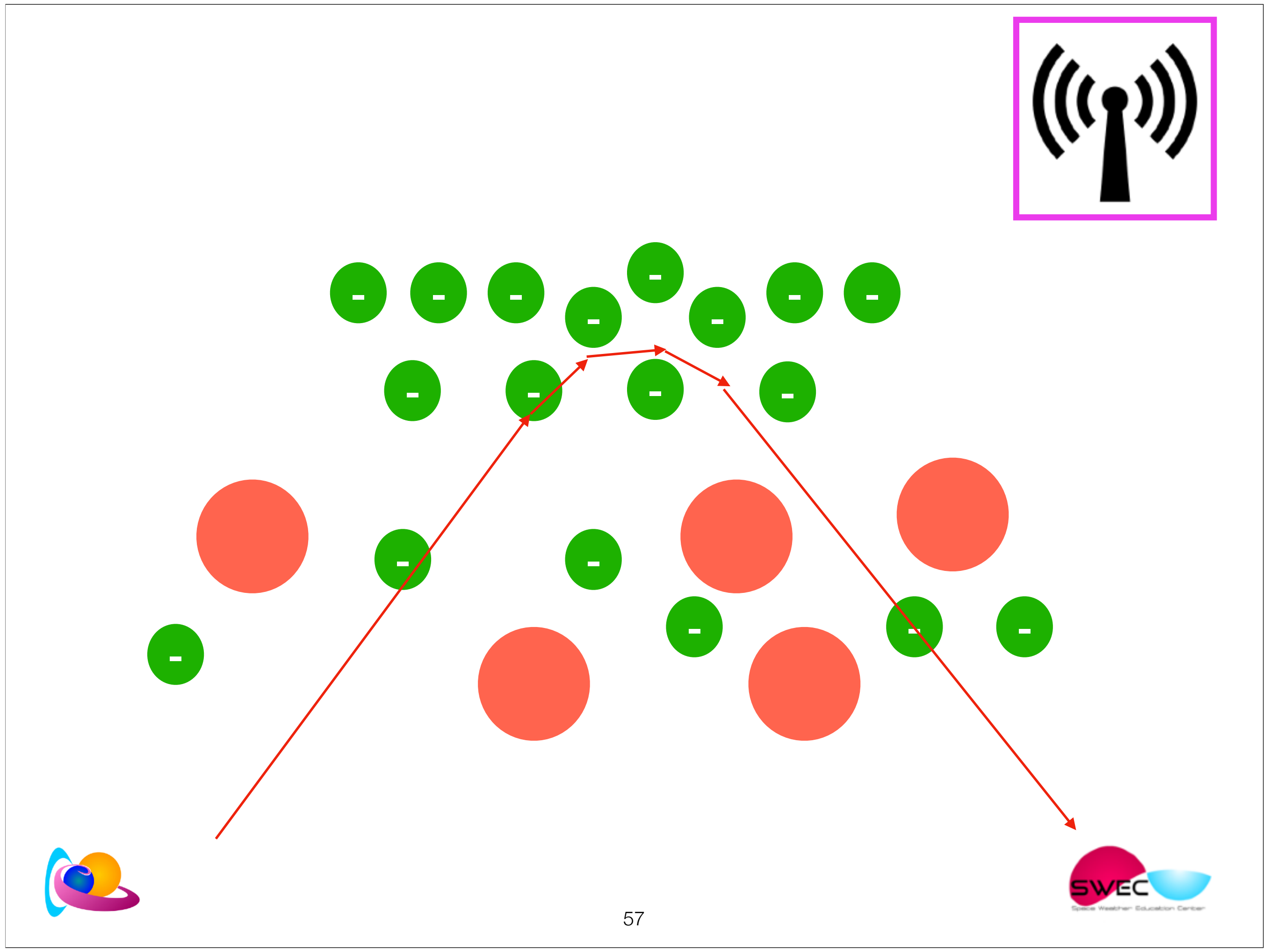


Radio wave makes the electrons move. Those moving electrons reproduce on their turn the radio signal and re-emitting it.

The ionosphere refracts radio waves
More refraction when higher the electron density or lower the frequency
When there are more electrons, the wave is more bent and again bent and again … until it is going down.
This is how reflection works in the ionosphere. It is a region full of magic (with a negative refractive index).

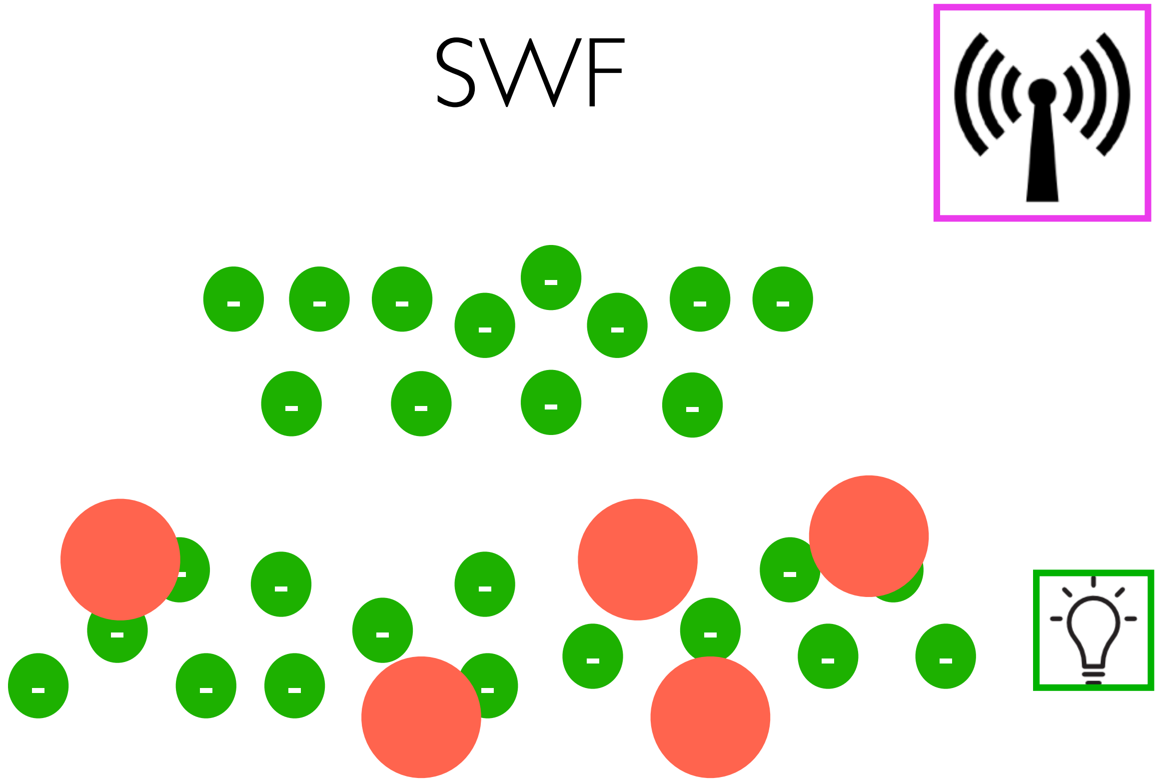


Neutrals are being present.



The radio wave also meets electrons in the D-layer. These electrons can't move as much due to the neutral —> absorption. Luckily, there are not many electrons and the absorption is minimal.

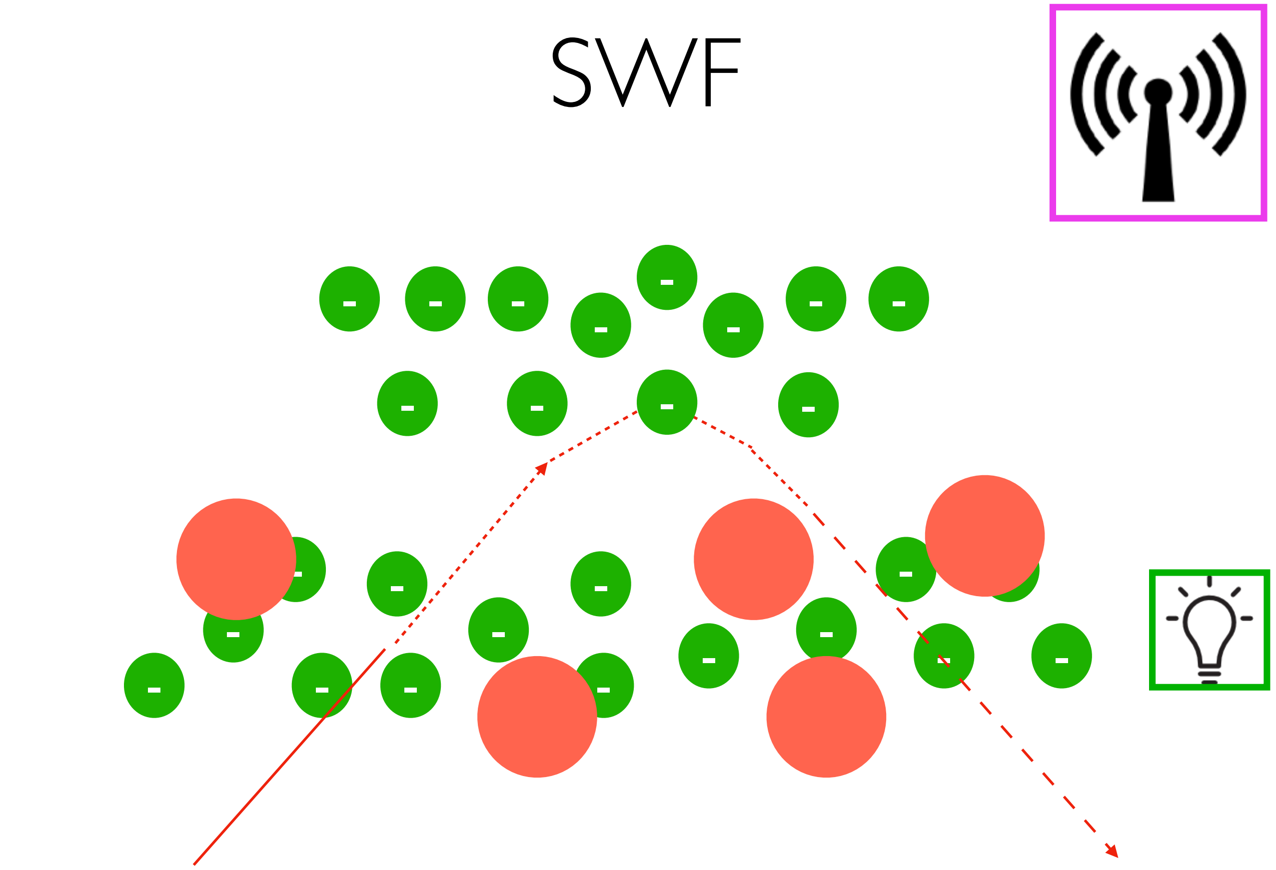
SWF



The incoming solar energetic particles ionise the D-layer.

The radio wave meets more electrons in the D-layer. During each encounter, the wave is being absorbed.

SWF



The radio wave meets more electrons in the D-layer. During each encounter, the wave is being absorbed.

After Mother's day storm - May 15, 2024

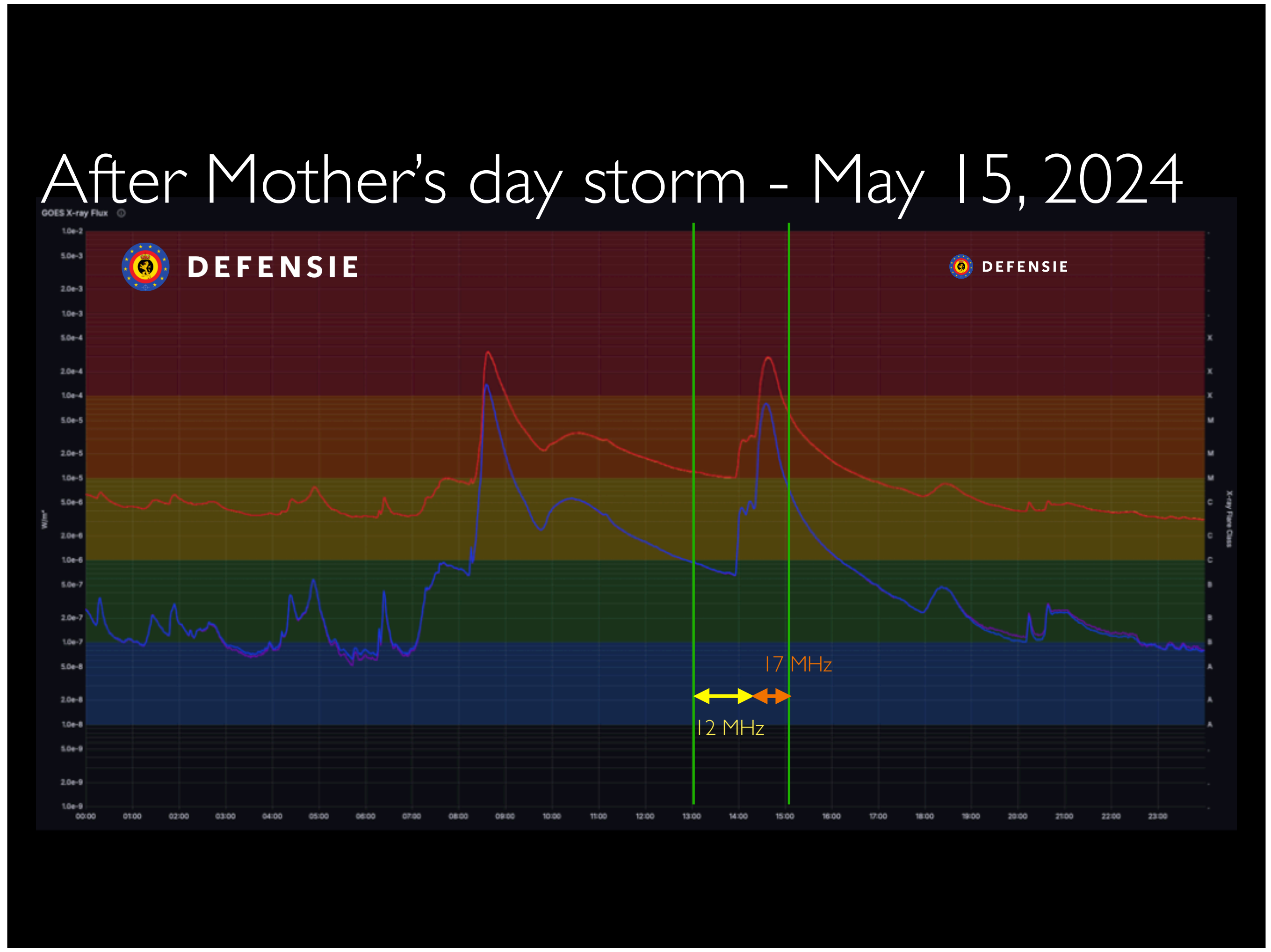
DEFENSIE

15 mei was een test tussen België en Canada.

15 mei was een test tussen België en Canada.

We hebben toen getest van 13u tot laat in de avond en niets heeft gewerkt. Dat heeft een aantal redenen, maar ik ben ervan overtuigd dat SWx er een belangrijke rol in heeft gespeeld.
13u-14u: Gestart op 12 MHz, mogelijks niet een ideale frequentie, maar ik denk het eigenlijk wel. Ik denk dat er hier niets gelukt was wegens andere verkeerde instellingen. Rond 14u zijn ze dan overgeschakeld naar 17 MHz, maar het is net op dat moment dat er een M class flare begon, gevolgd door een X class flare! Spreekt voor zich dat er met die ionosfeer niet te veel meer aan te vangen viel.
Men is dan blijven testen op 17 MHz, maar dat is waarschijnlijk al te hoogfrequent, en zeker naar de avond toe.

De volgende dag heeft men de testen hervat in de namiddag, toen was er een Kp van 4, ook toen kwam er niets door.



15 mei was een test tussen België en Canada.

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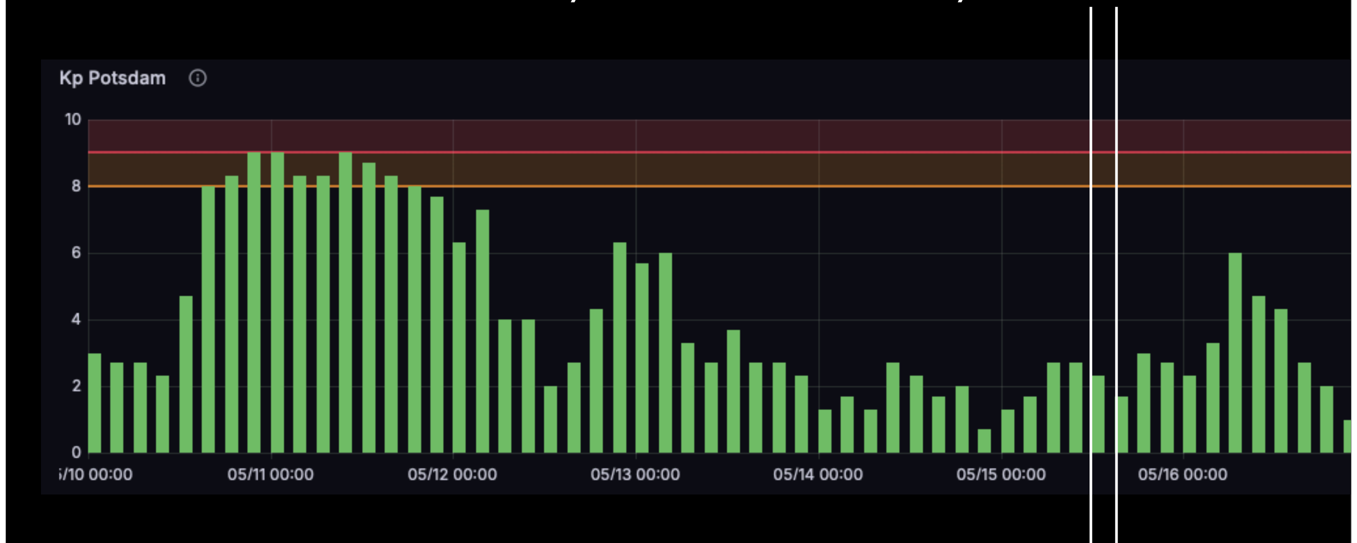
After Mother's day storm - May 15, 2024



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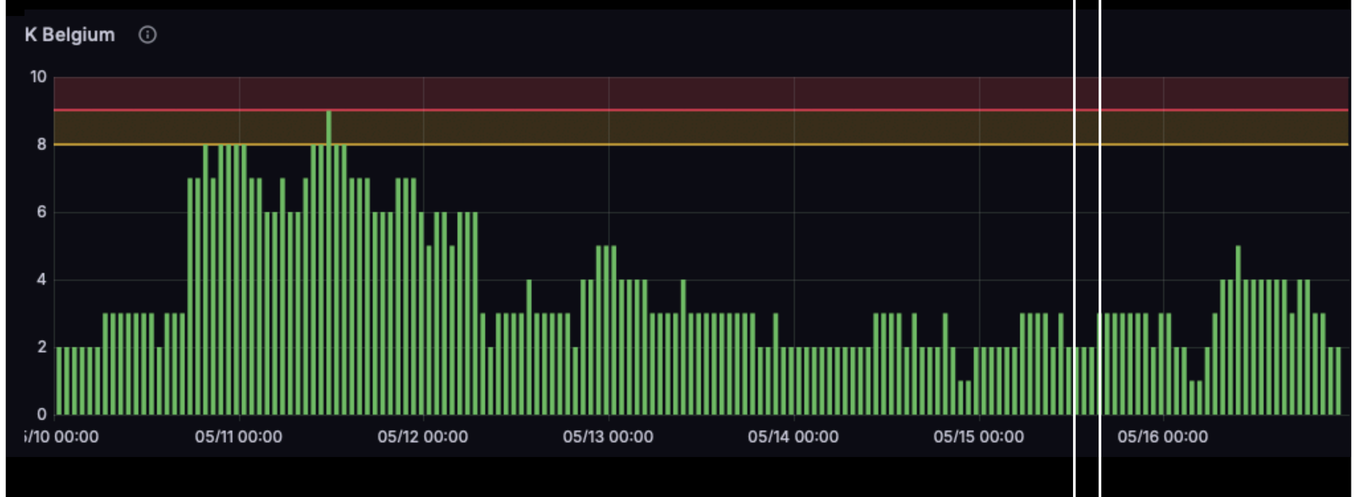

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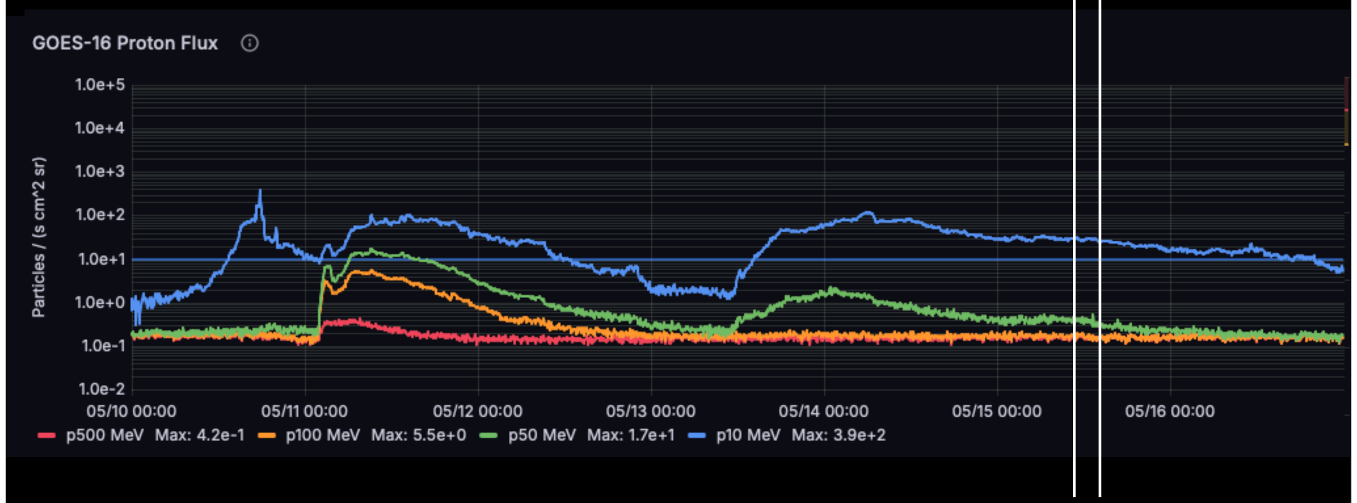

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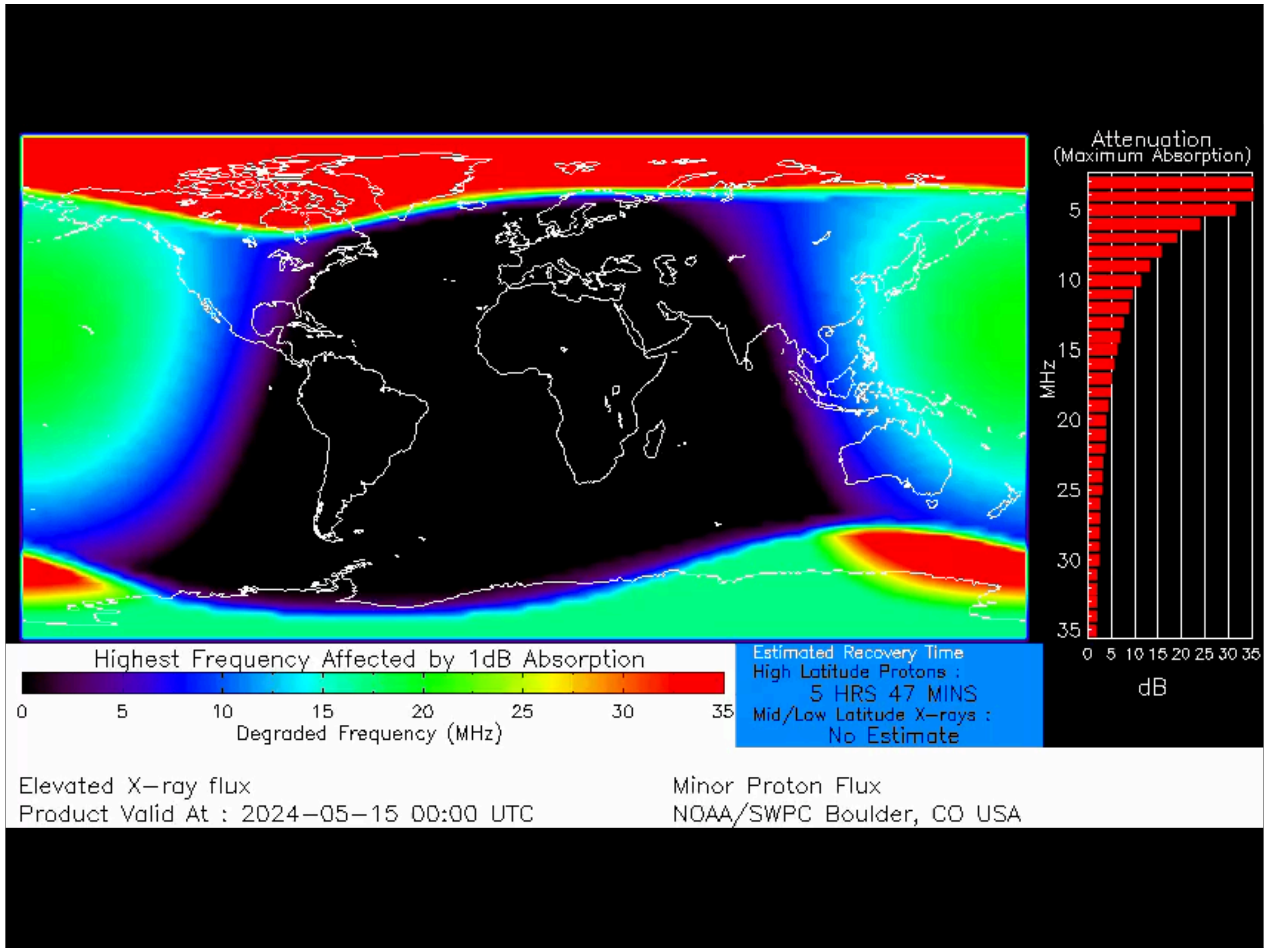
Attenuation
(Maximum Absorption)
MHz
5
10
15
20
25
30
35
dB
0 5 10 15 20 25 30 35
Highest Frequency Affected by 1dB Absorption
0 5 10 15 20 25 30 35
Degraded Frequency (MHz)
Estimated Recovery Time
High Latitude Protons :
5 HRS 47 MINS
Mid/Low Latitude X-rays :
No Estimate
Elevated X-ray flux
Product Valid At : 2024-05-15 00:00 UTC
Minor Proton Flux
NOAA/SWPC Boulder, CO USA