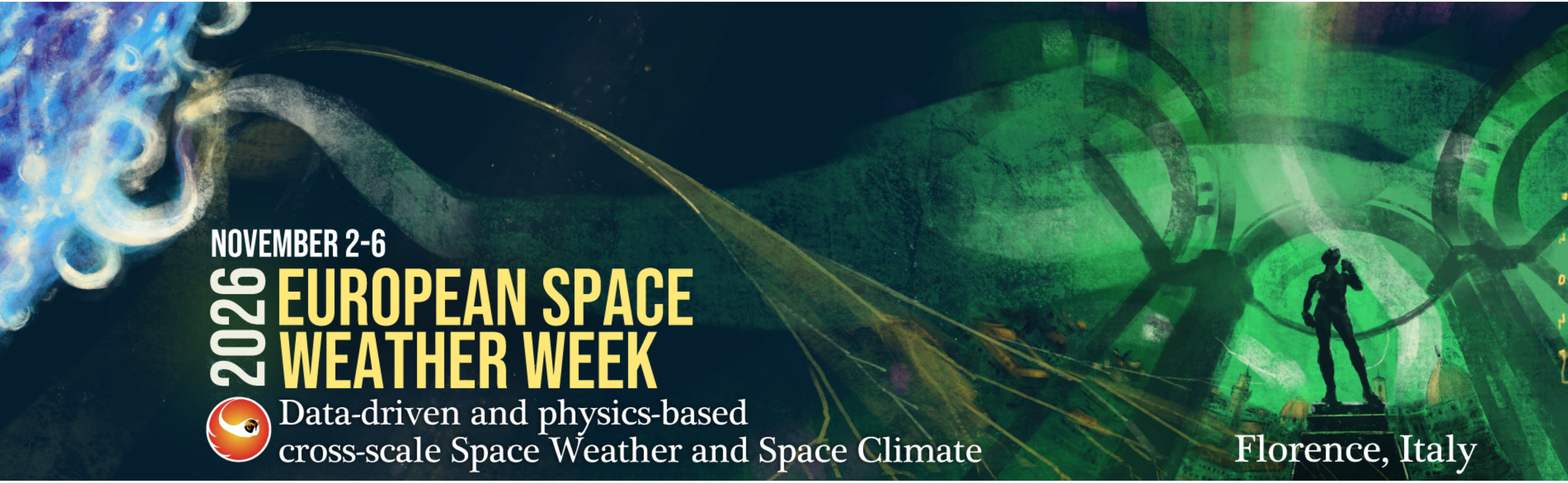
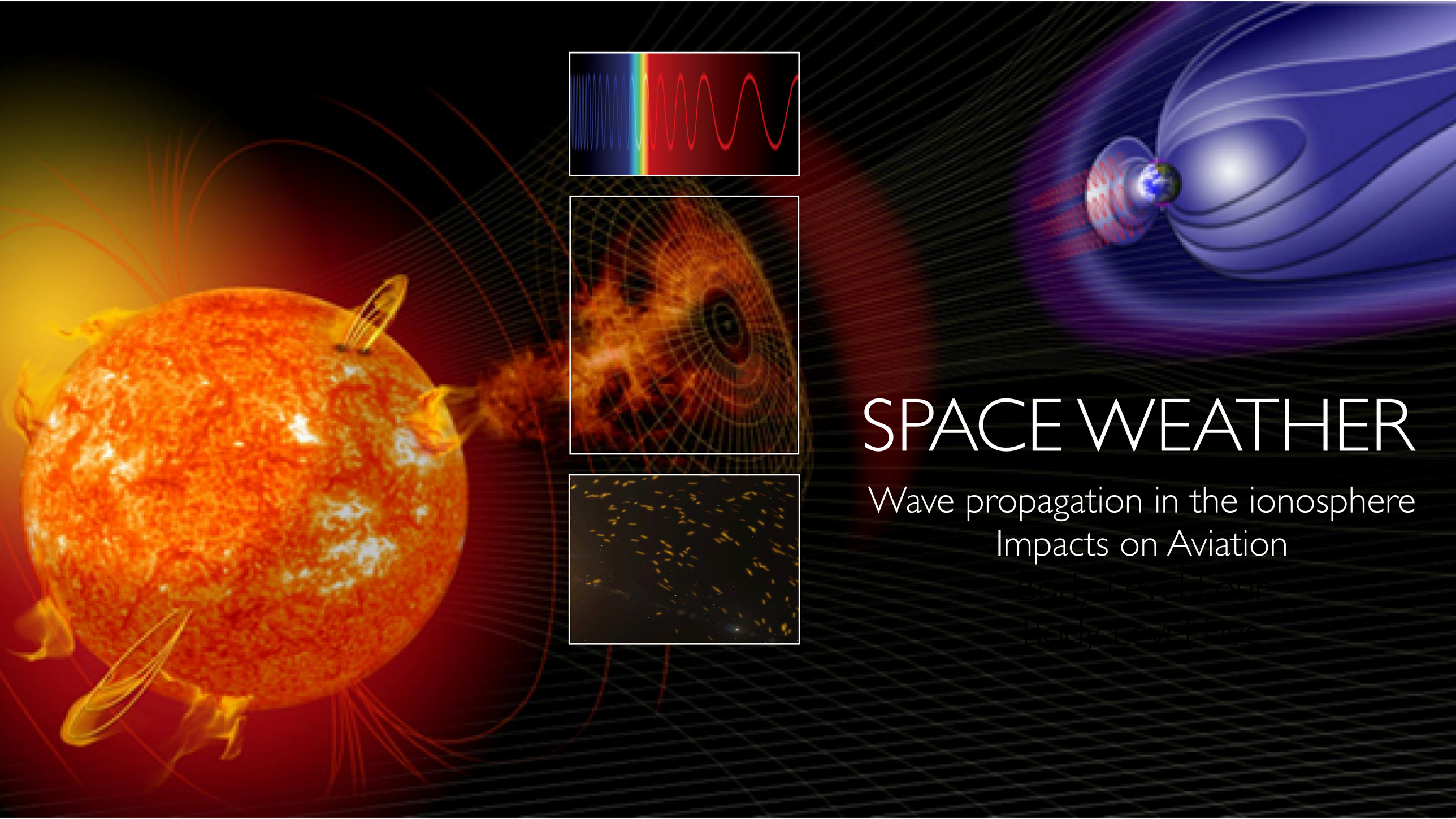
Space Weather Training Course



e-swan

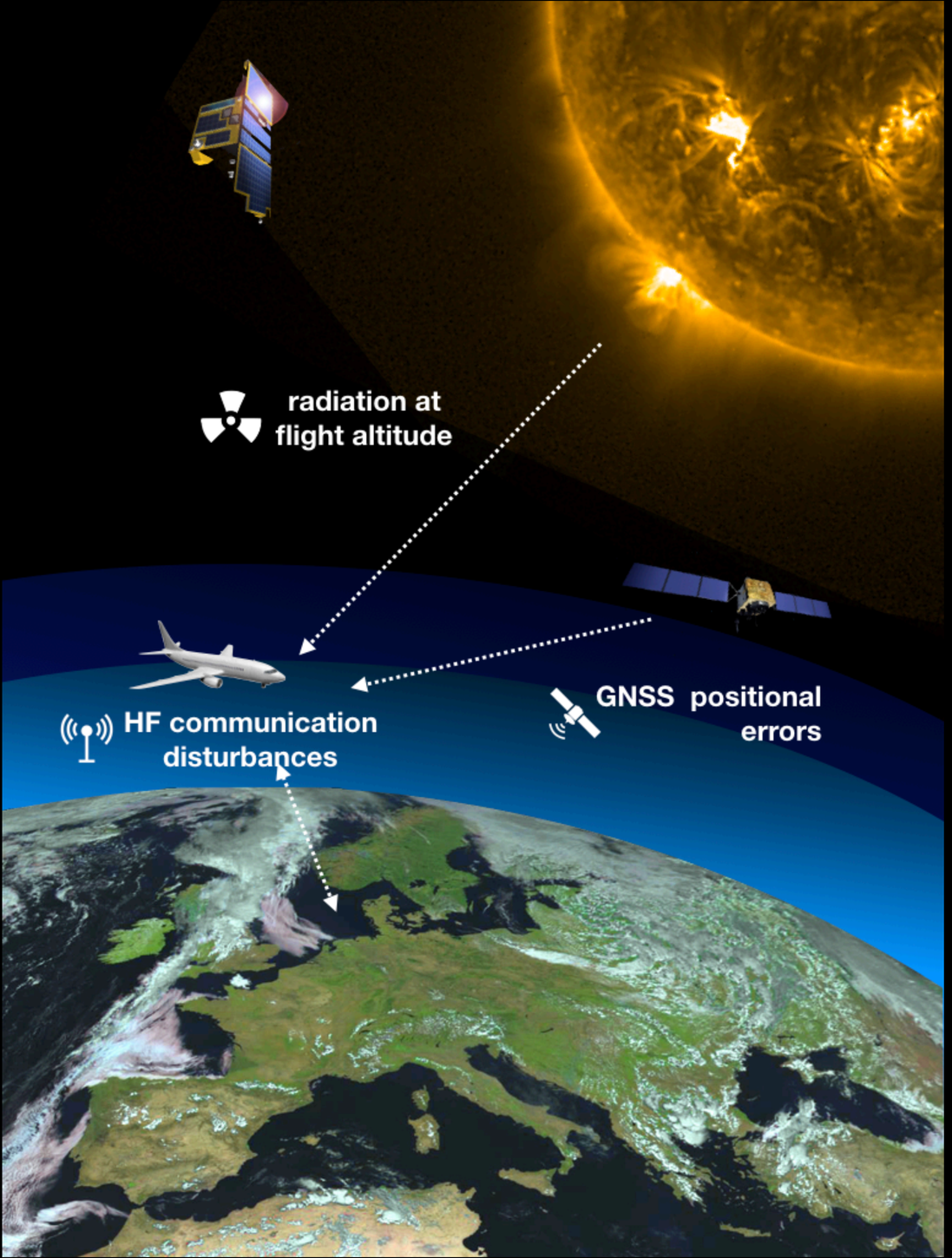
SWEC
Space Weather Education Centre

COMMUNITY COORDINATED MODELING CENTER



SPACE WEATHER

Wave propagation in the ionosphere
Impacts on Aviation

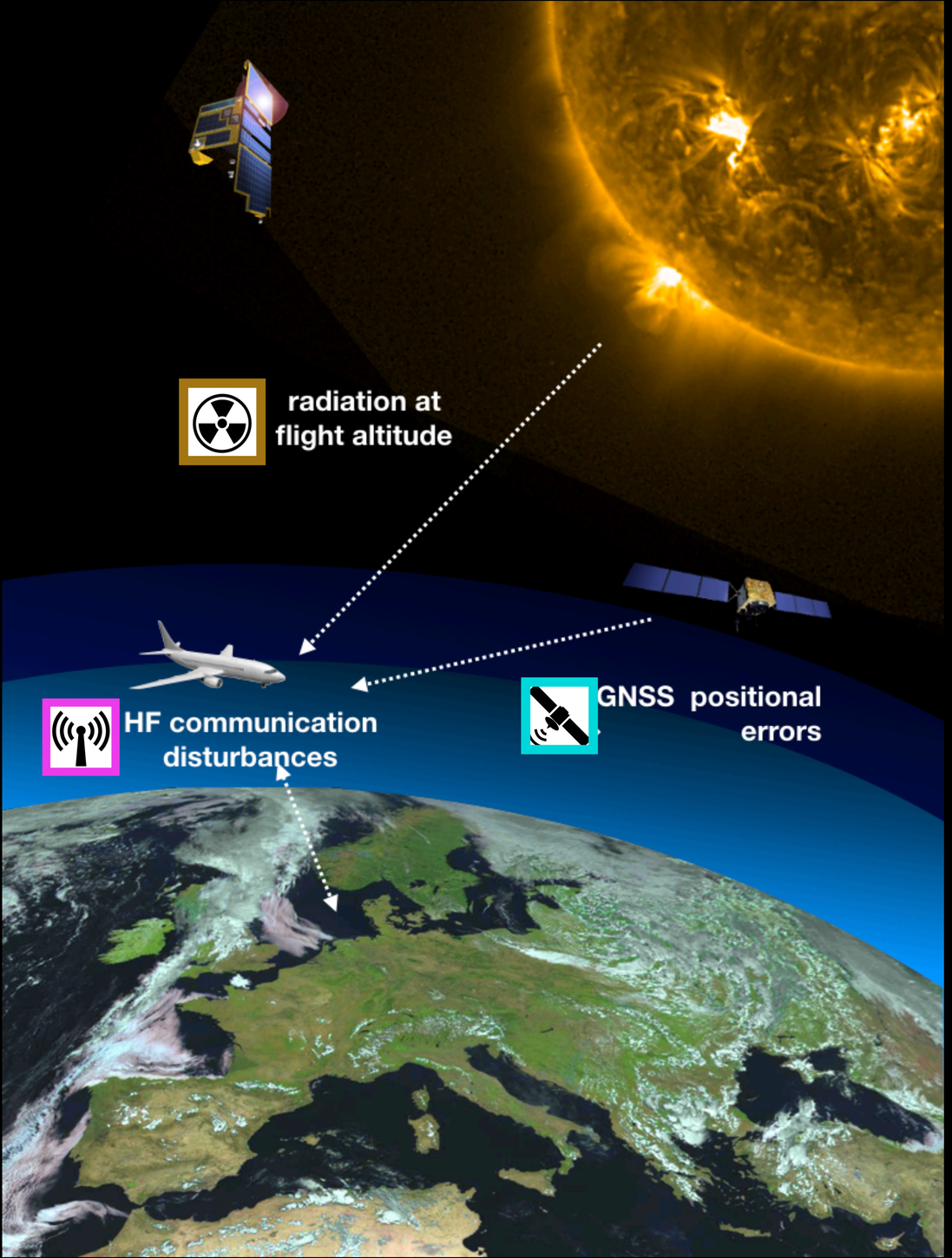


PECASUS

Partnership of Excellence for Civil Aviation SWx User Services

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

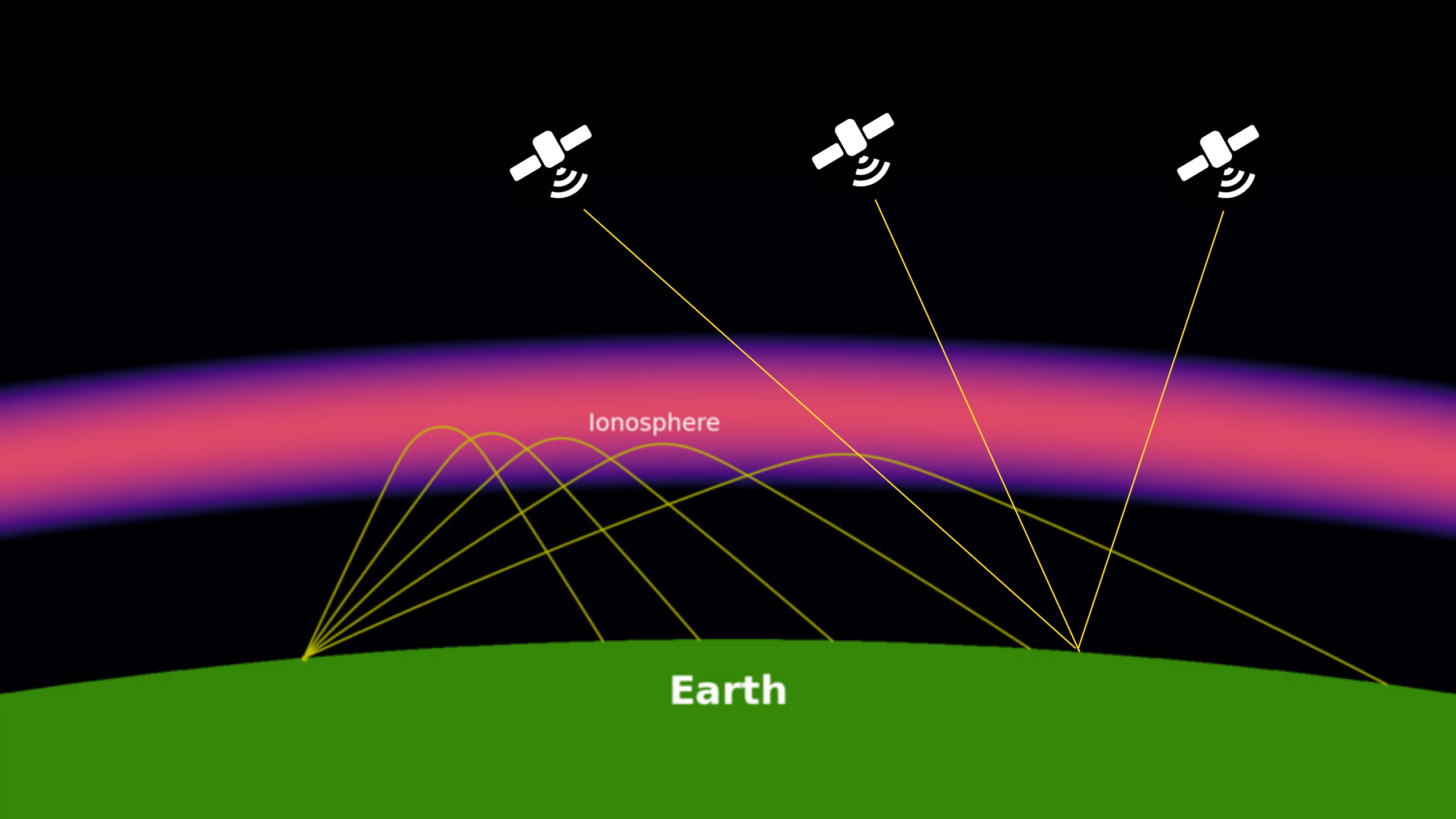
Petra Vanlommel, Christophe Marqué

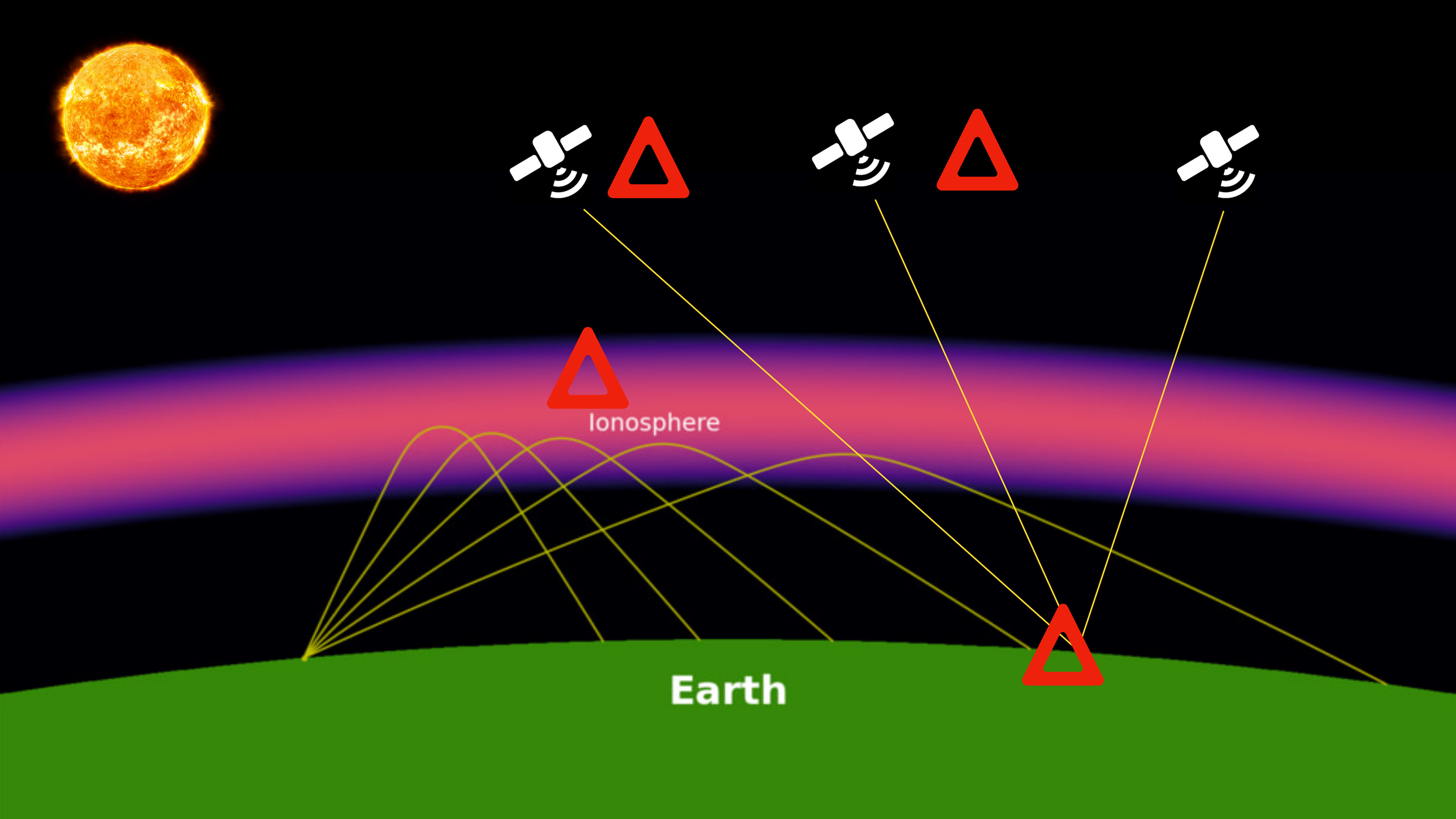


PECASUS

Partnership of Excellence for Civil Aviation SWx User Services

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

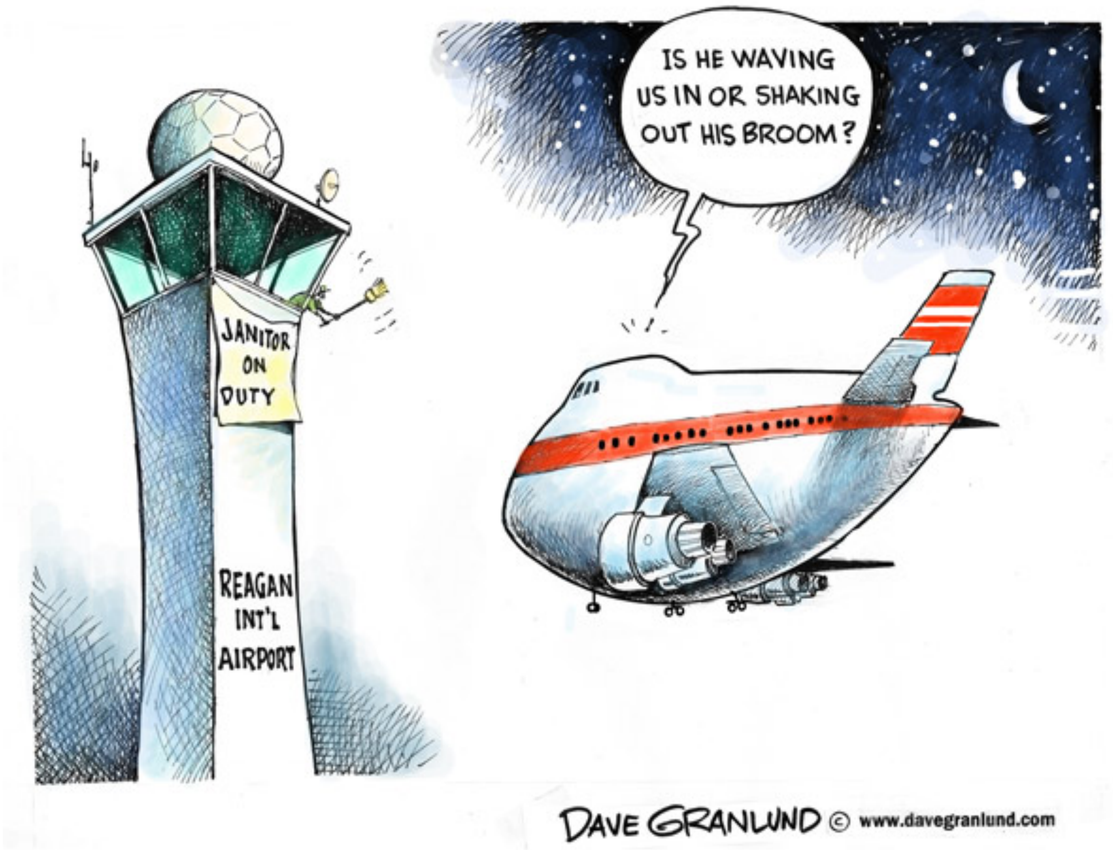

Ionosphere
Earth


Ionosphere
Earth

HF Advisory:

0000057501
FNXX02 EFKL 020814
SWX ADVISORY
DTG: 20260202/0814Z
SWXC: PECASUS
SWX EFFECT: HF COM
ADVISORY NR: 2026/63
OBS SWX: 02/0808Z MOD DAYSIDE
FCST SWX +6 HR: 02/1500Z NOT AVBL
FCST SWX +12 HR: 02/2100Z NOT AVBL
FCST SWX +18 HR: 03/0300Z NOT AVBL
FCST SWX +24 HR: 03/0900Z NOT AVBL
RMK: SPACE WEATHER EVENT (SOLAR FLARE) IN PROGRESS. IMPACT ON LOWER HF COM FREQUENCY BANDS EXPECTED
ON THE DAYLIGHT SIDE. HIGHER FREQUENCY BANDS MAY BE LESS
IMPACTED.
NXT ADVISORY: WILL BE ISSUED BY 20260202/1408Z=

Frequencies used in aviation





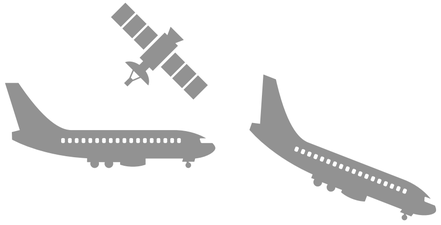
Surveillance
SSR 1030 - 1090 MHz
PSR 1215 -1350 MHz
2700 - 2900 MHz



Communications
118 - 137 MHz
226 - 400 MHz
410 - 450 MHz

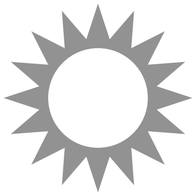


GNSS
GPS
GALILEO
GLONASS
1164 - 1610 MHz



Navigation
960 - 1215 MHz
329 - 335 MHz
108 - 118 MHz
75 MHz

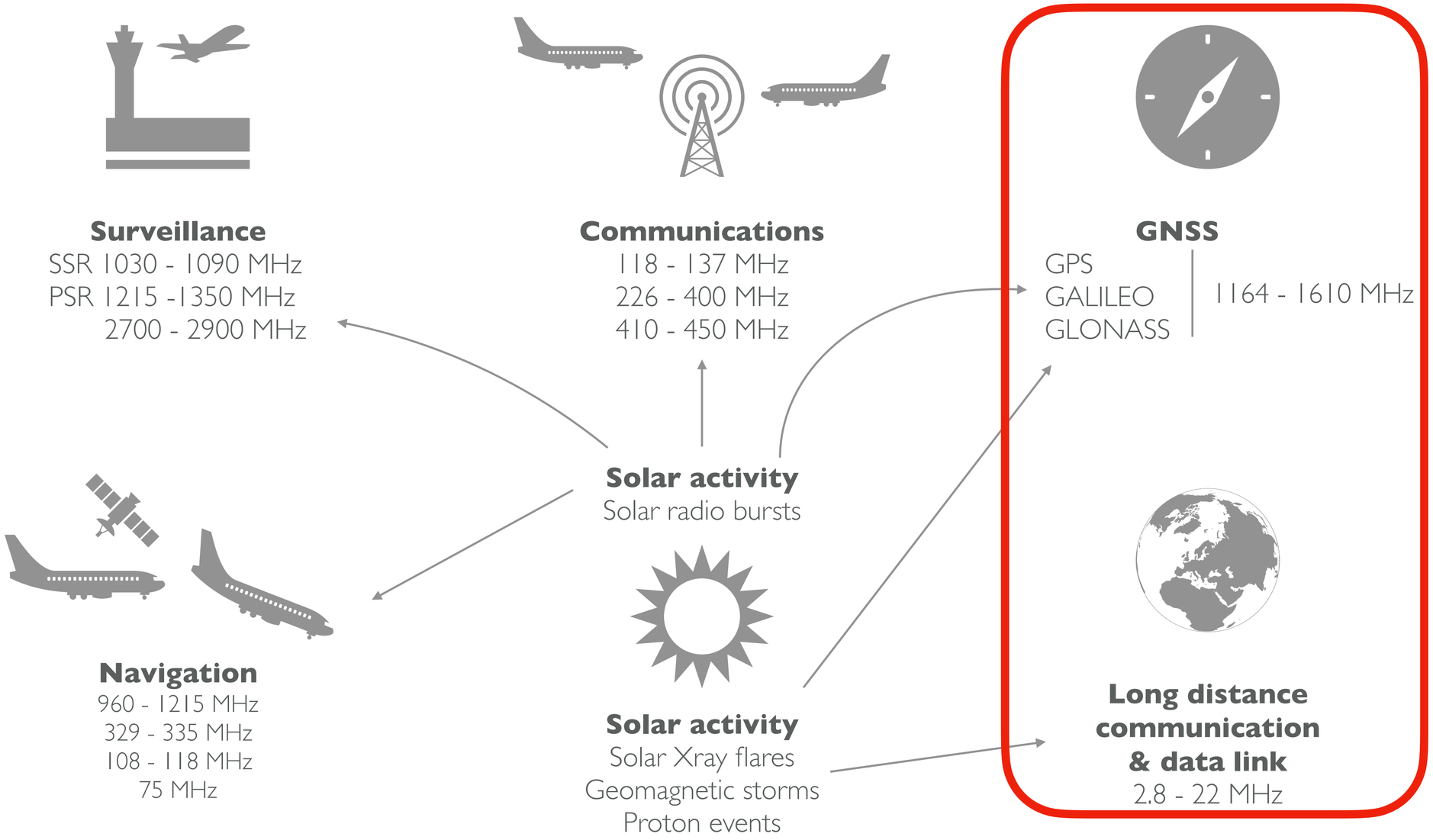
Solar activity
Solar radio bursts



Solar activity
Solar Xray flares
Geomagnetic storms
Proton events



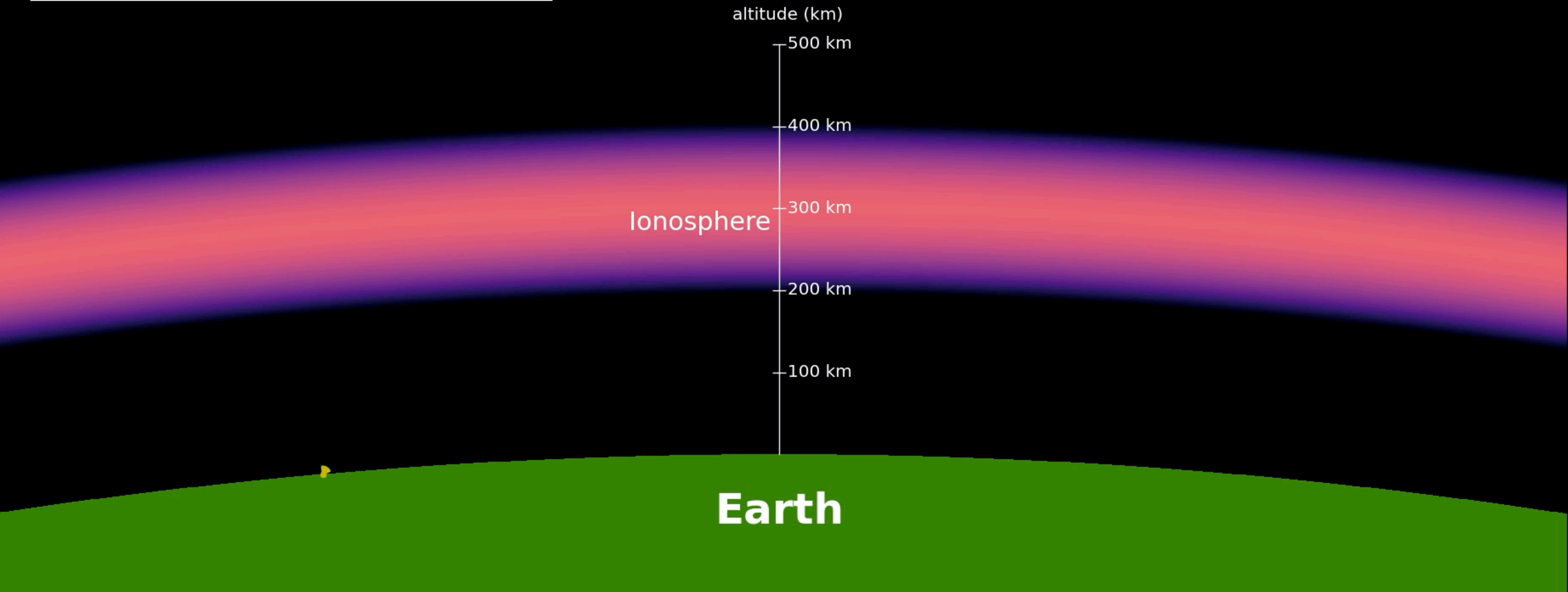
Long distance communication & data link
2.8 - 22 MHz


Surveillance
SSR 1030 - 1090 MHz
PSR 1215 -1350 MHz
2700 - 2900 MHz
Communications
118 - 137 MHz
226 - 400 MHz
410 - 450 MHz
GNSS
GPS
GALILEO
GLONASS
1164 - 1610 MHz
Solar activity
Solar radio bursts
Navigation
960 - 1215 MHz
329 - 335 MHz
108 - 118 MHz
75 MHz
Solar activity
Solar Xray flares
Geomagnetic storms
Proton events
Long distance communication & data link
2.8 - 22 MHz

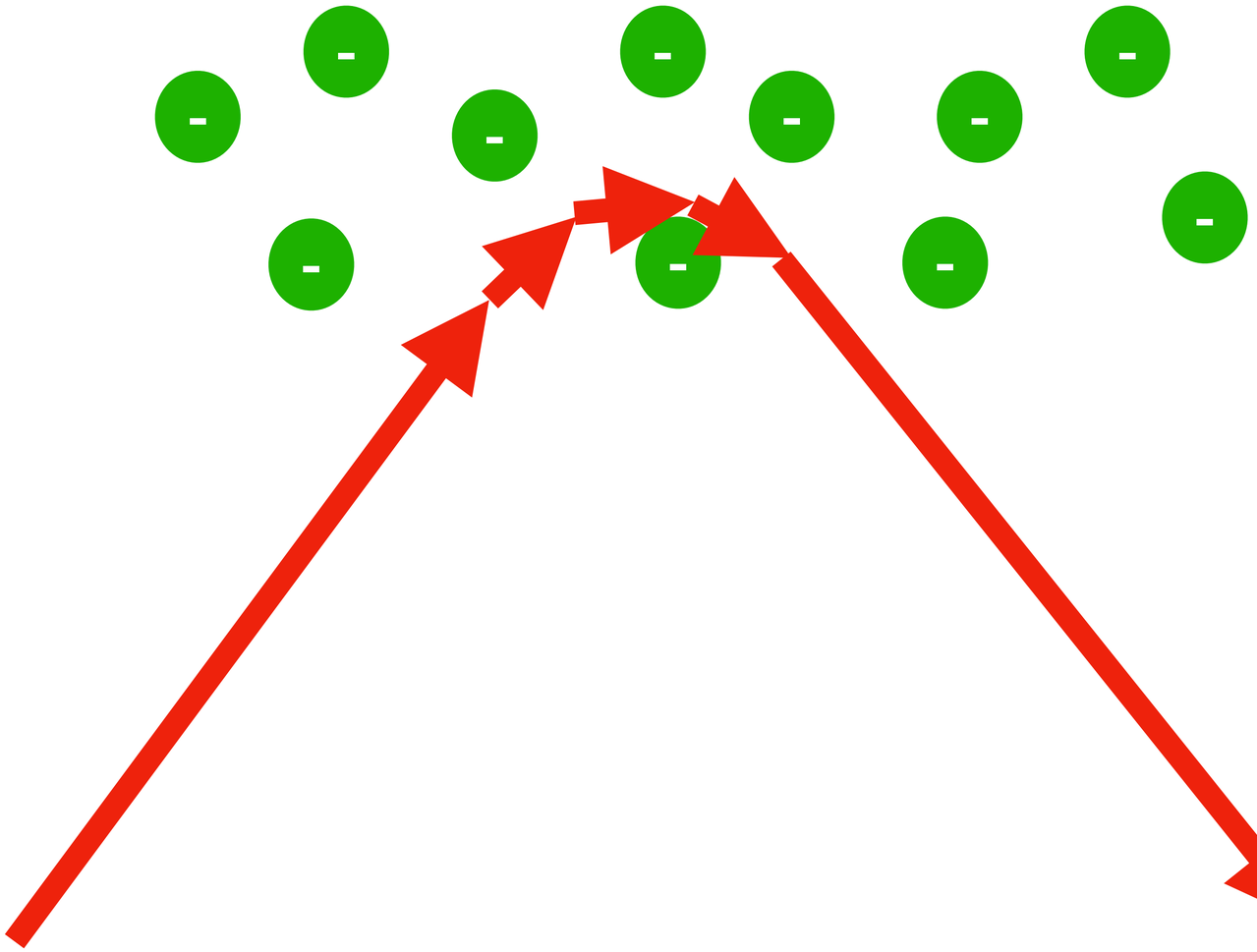
The plasma frequency affects the refractive index of the medium

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

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



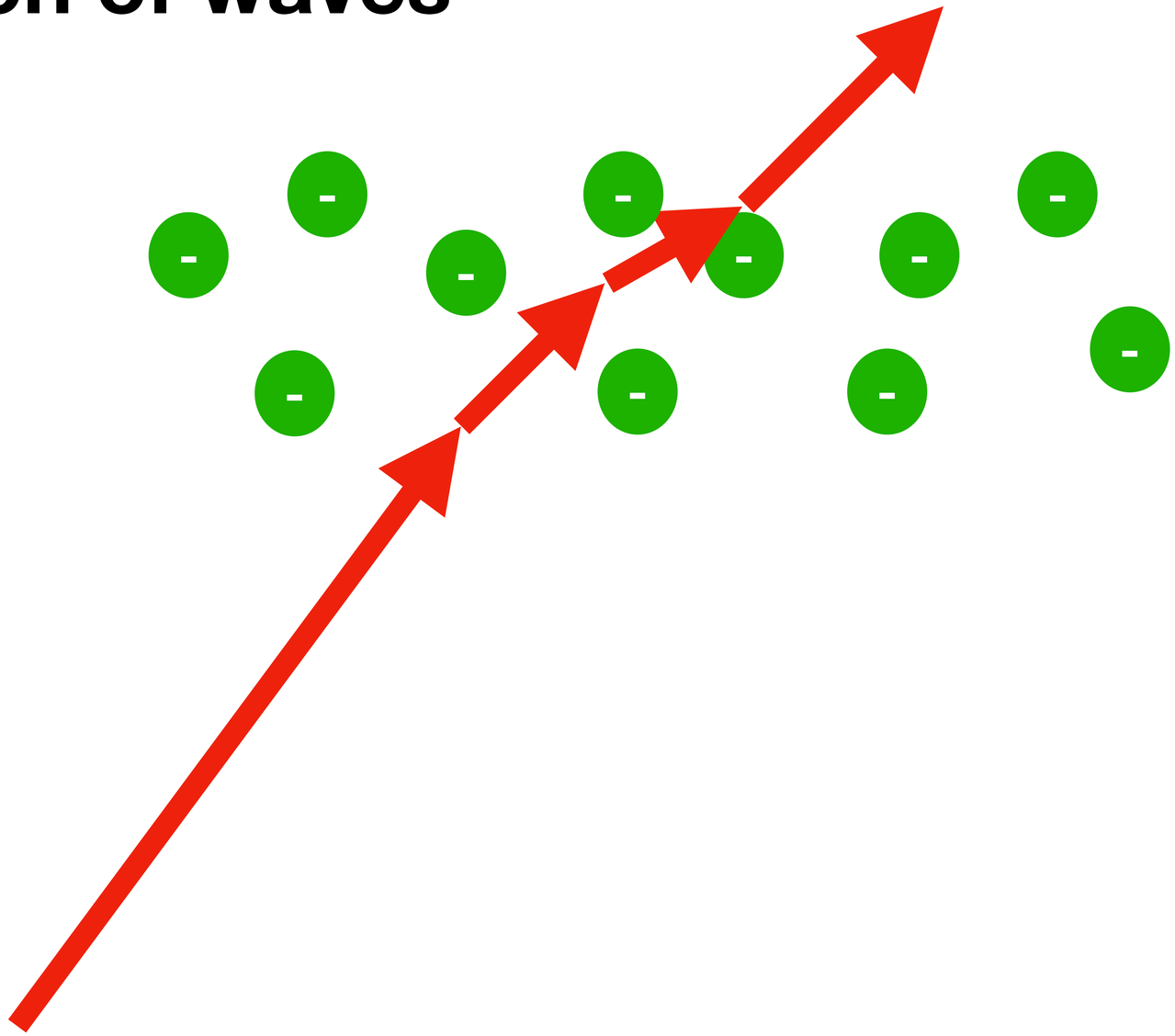
Reflection of waves





Transmission of waves





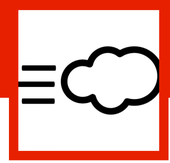
IMPACT

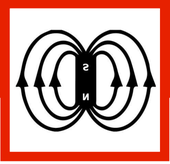


Ionisation

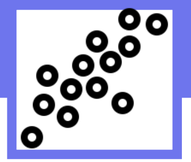


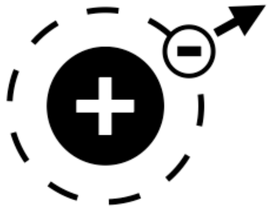
Ionisation
Particle content

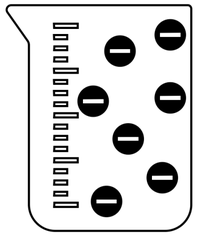


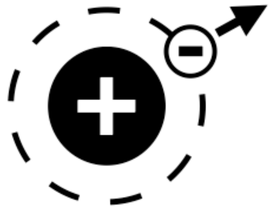


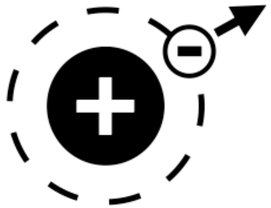
Ionisation
Particle Radiation





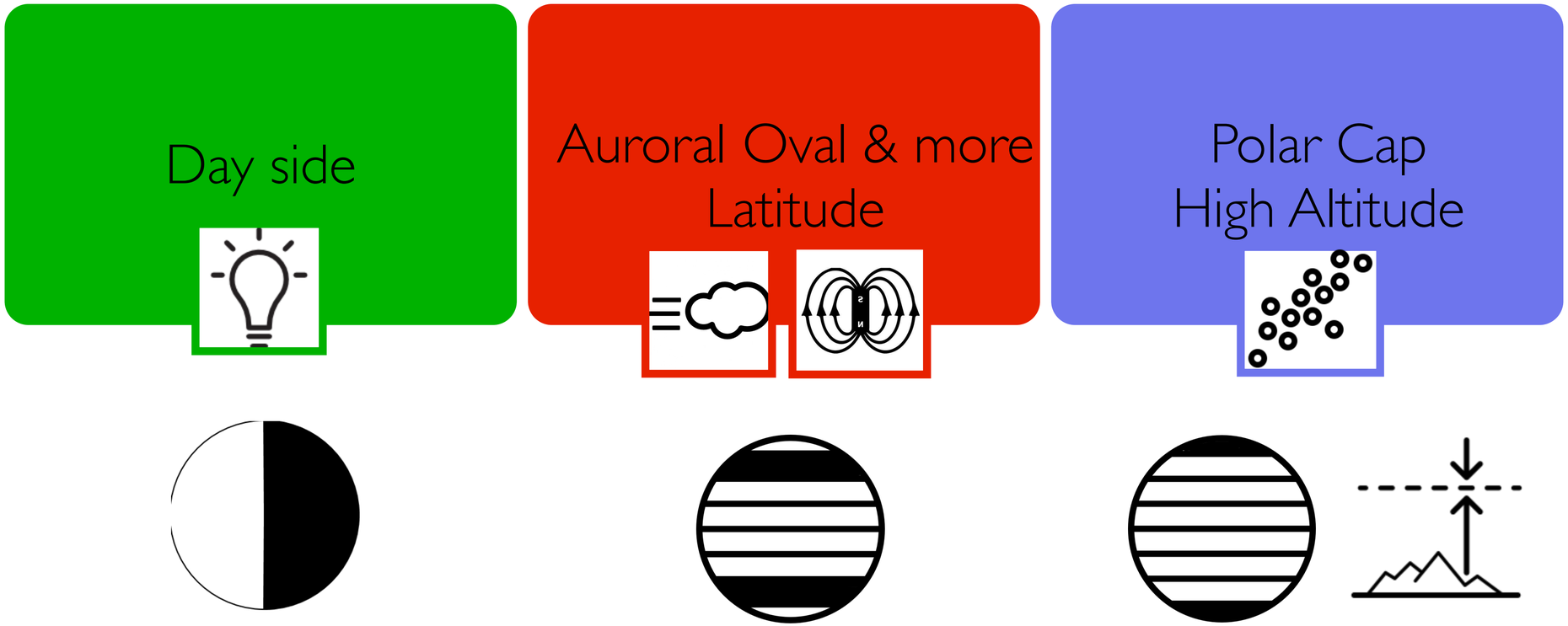








AREA OF IMPACT



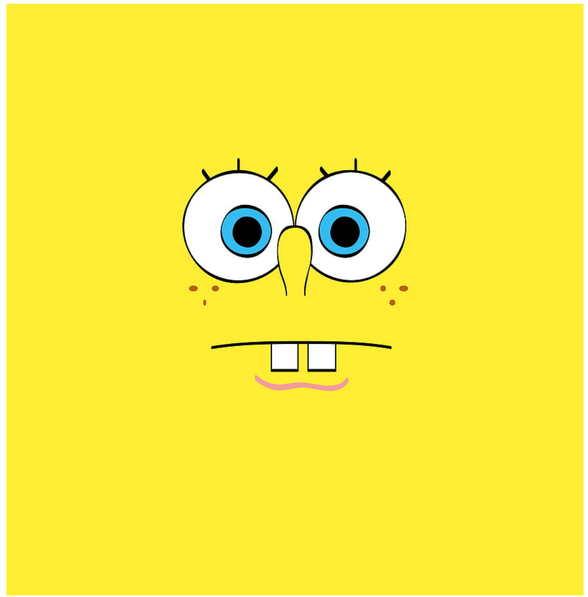


Impacts on waves



Impacts on waves

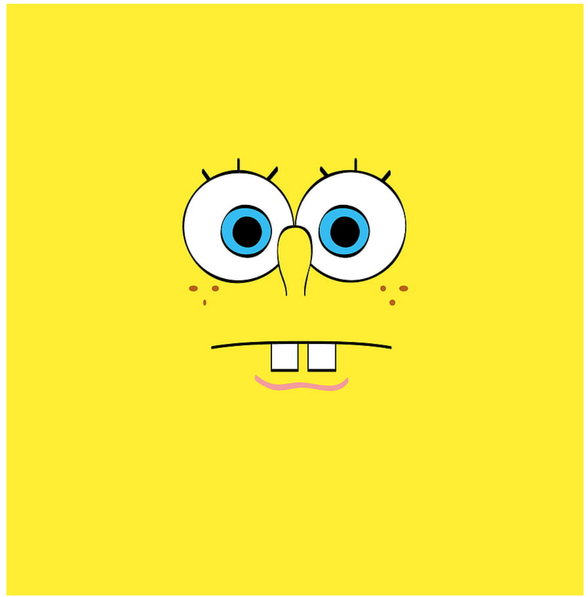
Absorption





Impacts on waves

Absorption



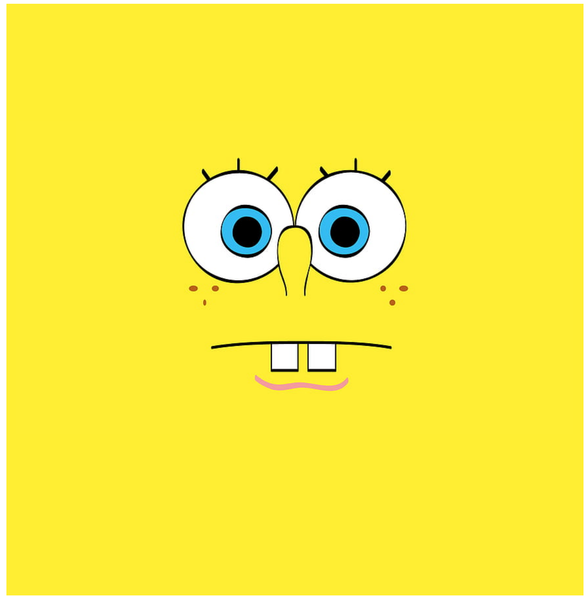
No reflection





Impacts on waves

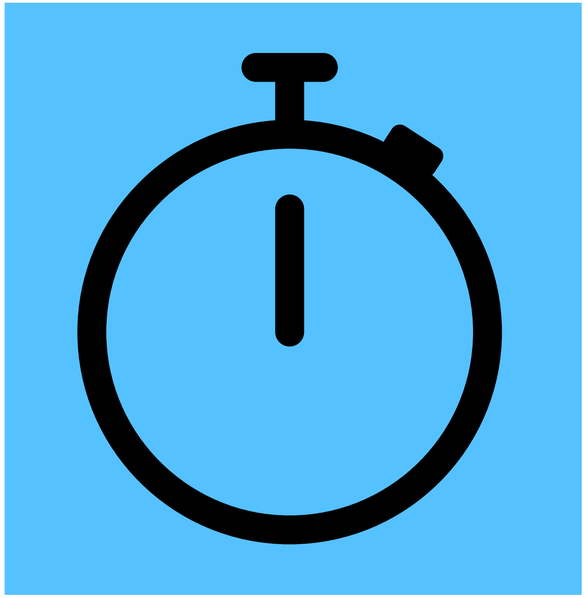
Absorption



No reflection



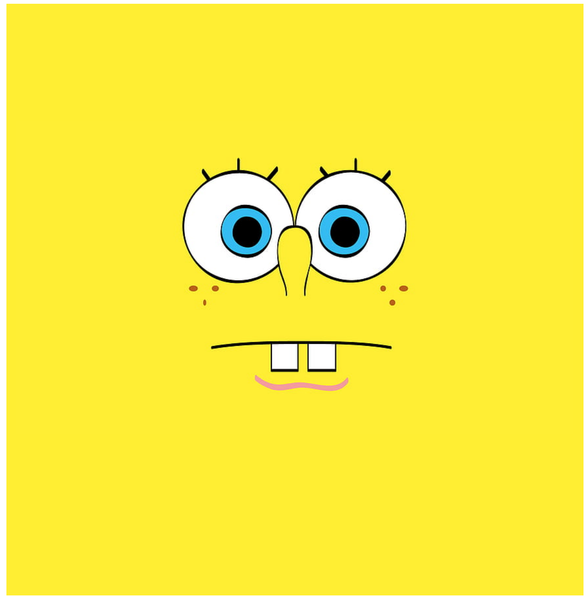
Delay





Impacts on waves

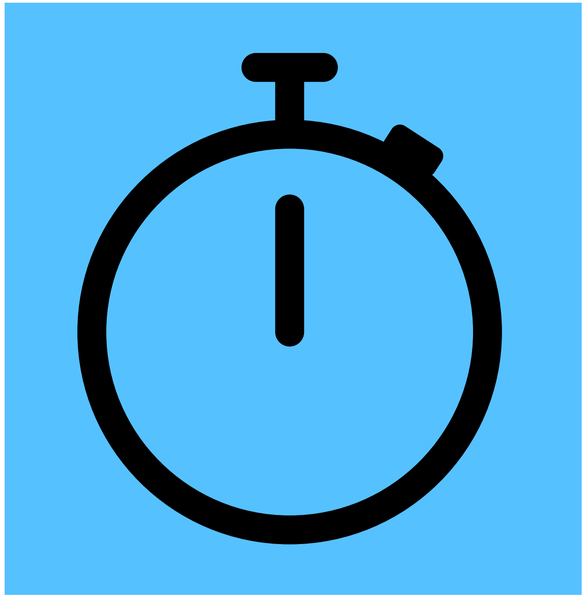
Absorption



No reflection



Delay

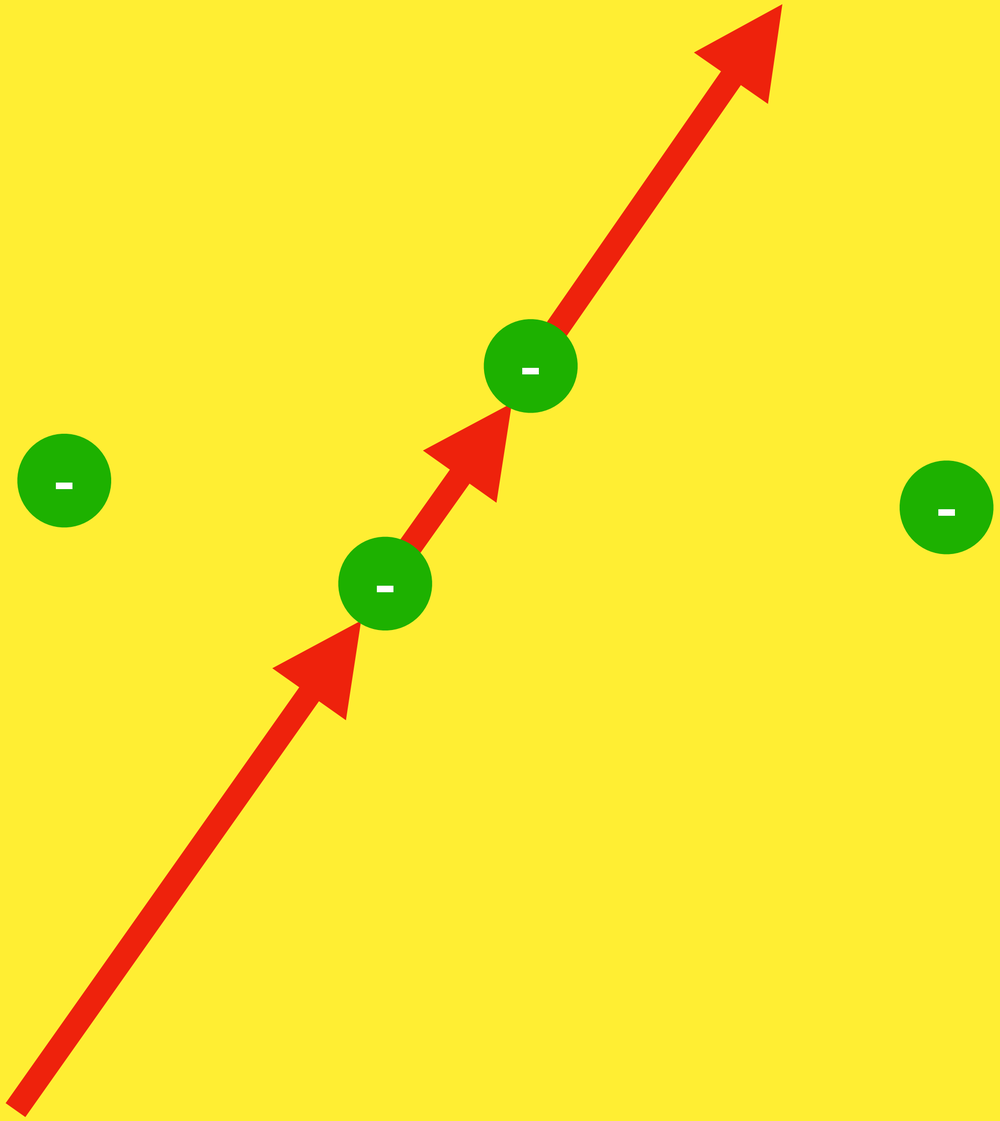


Scintillation

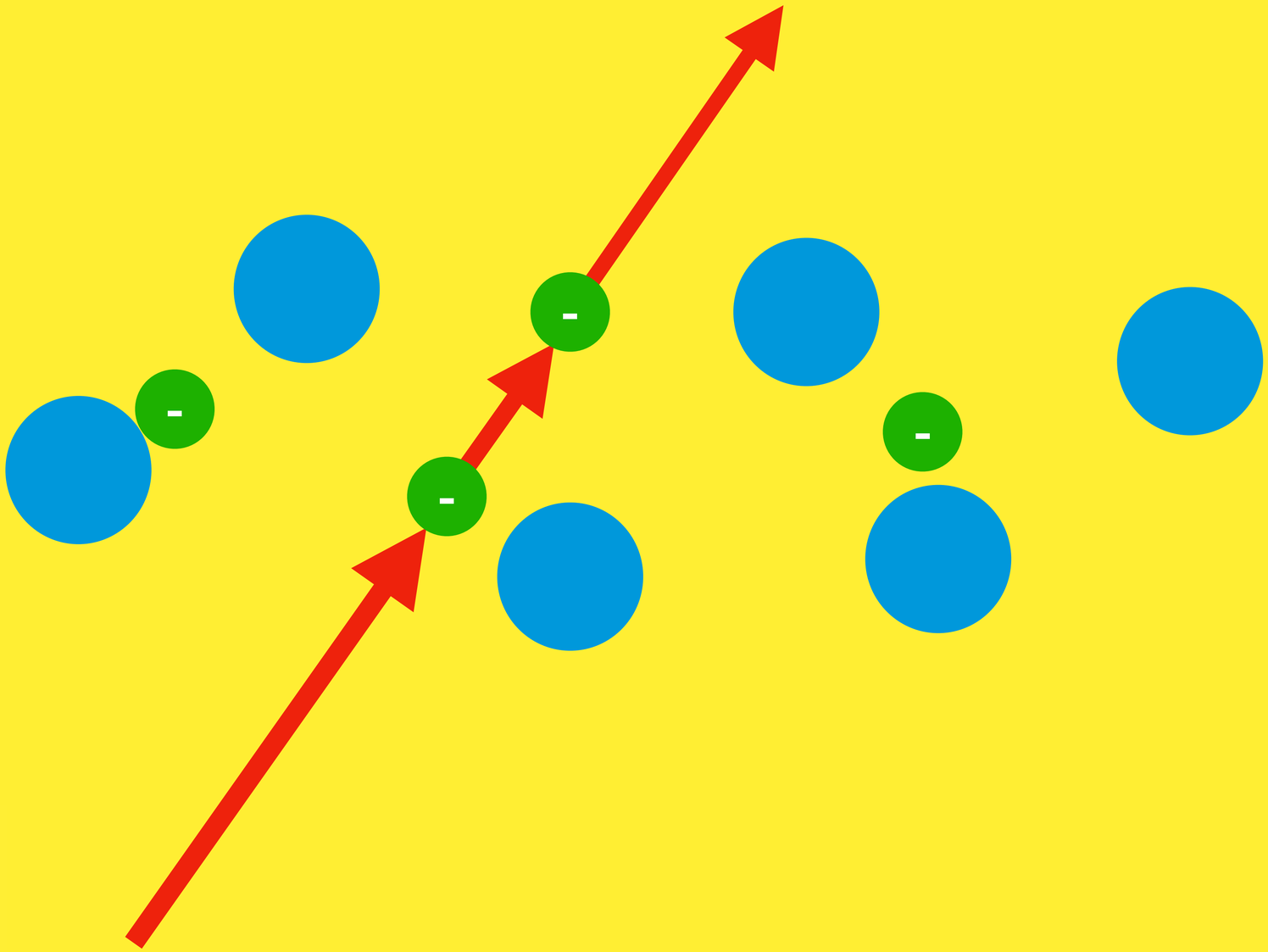


Impact: Absorption of HF waves

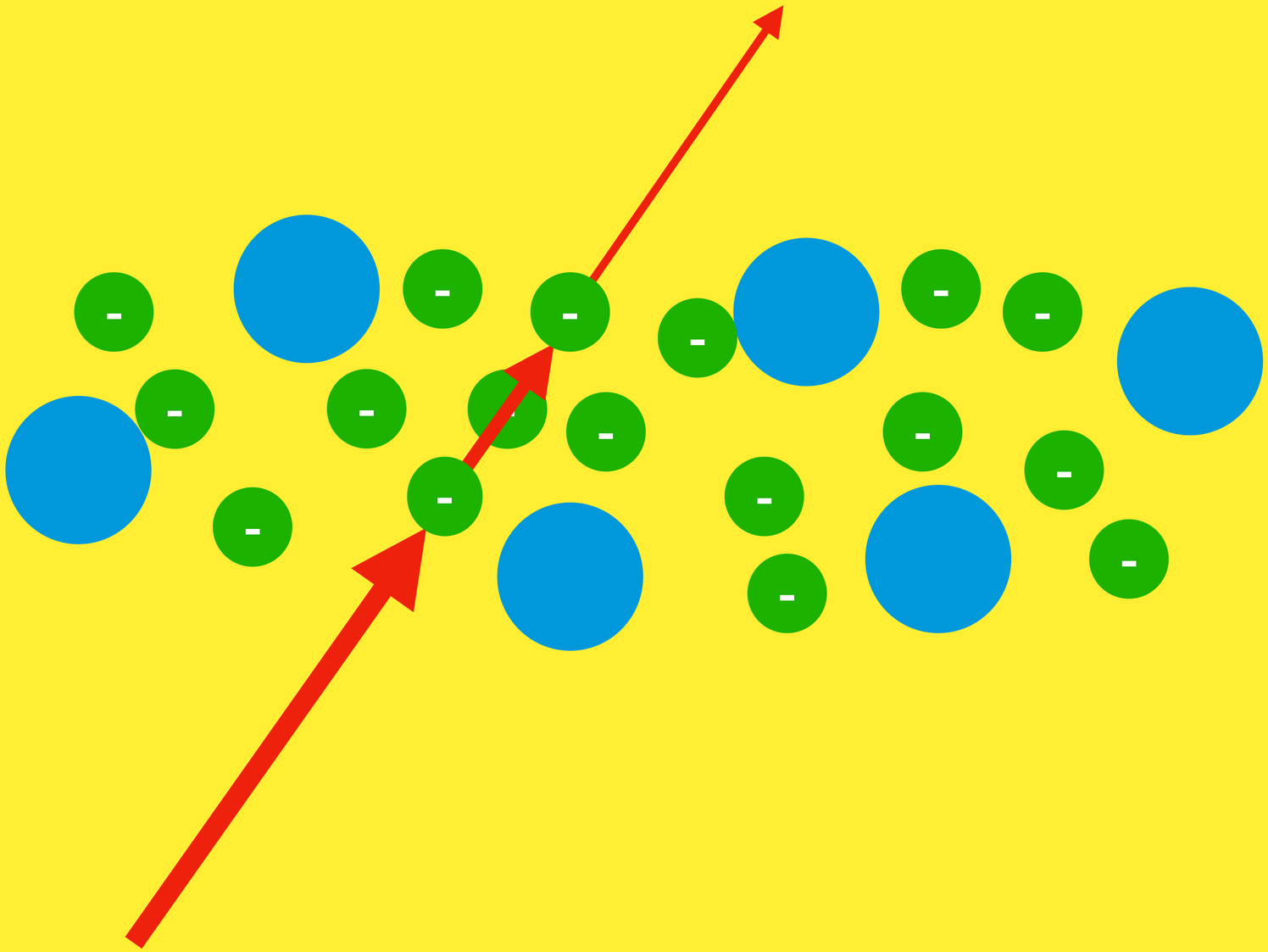






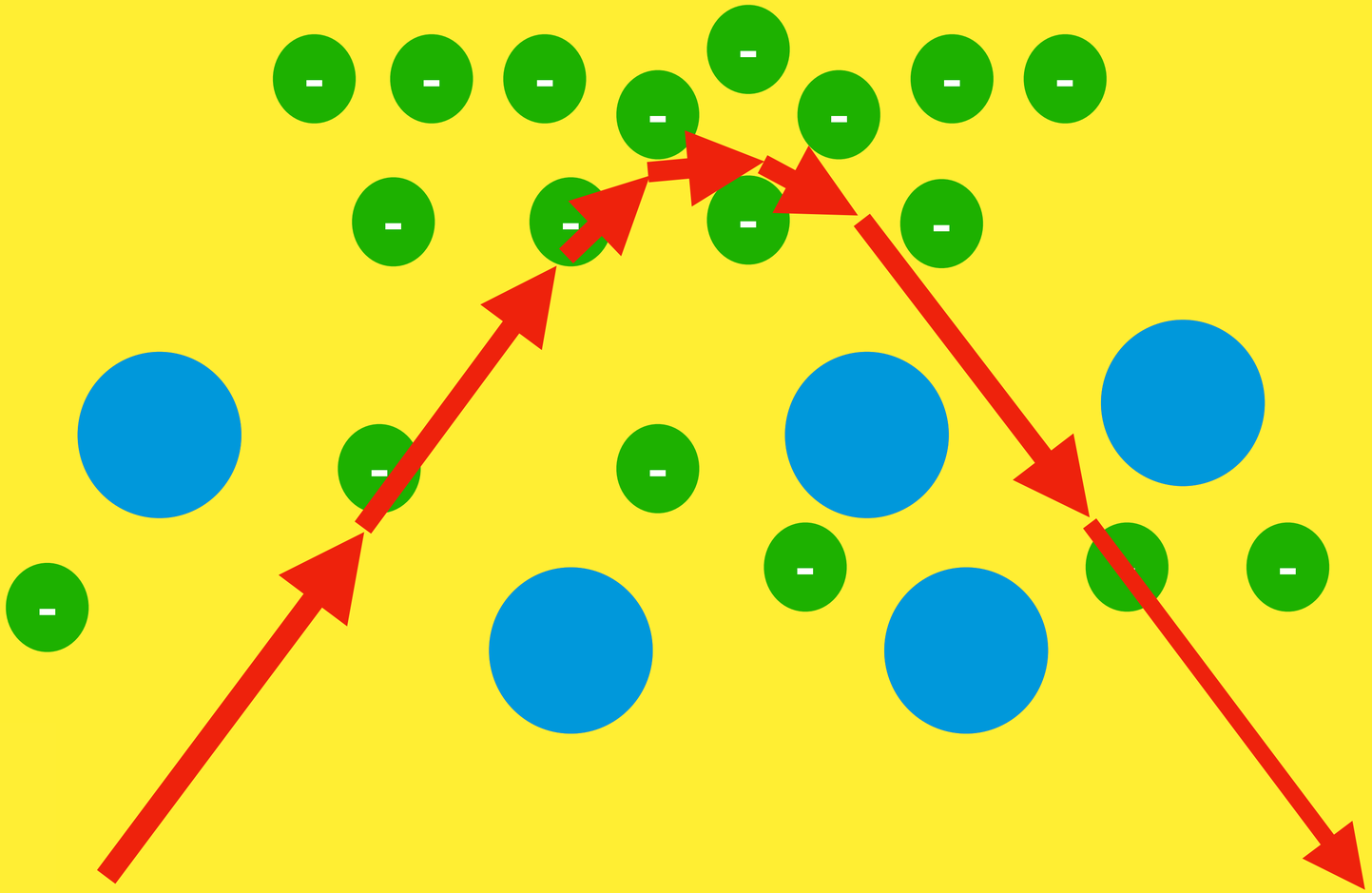






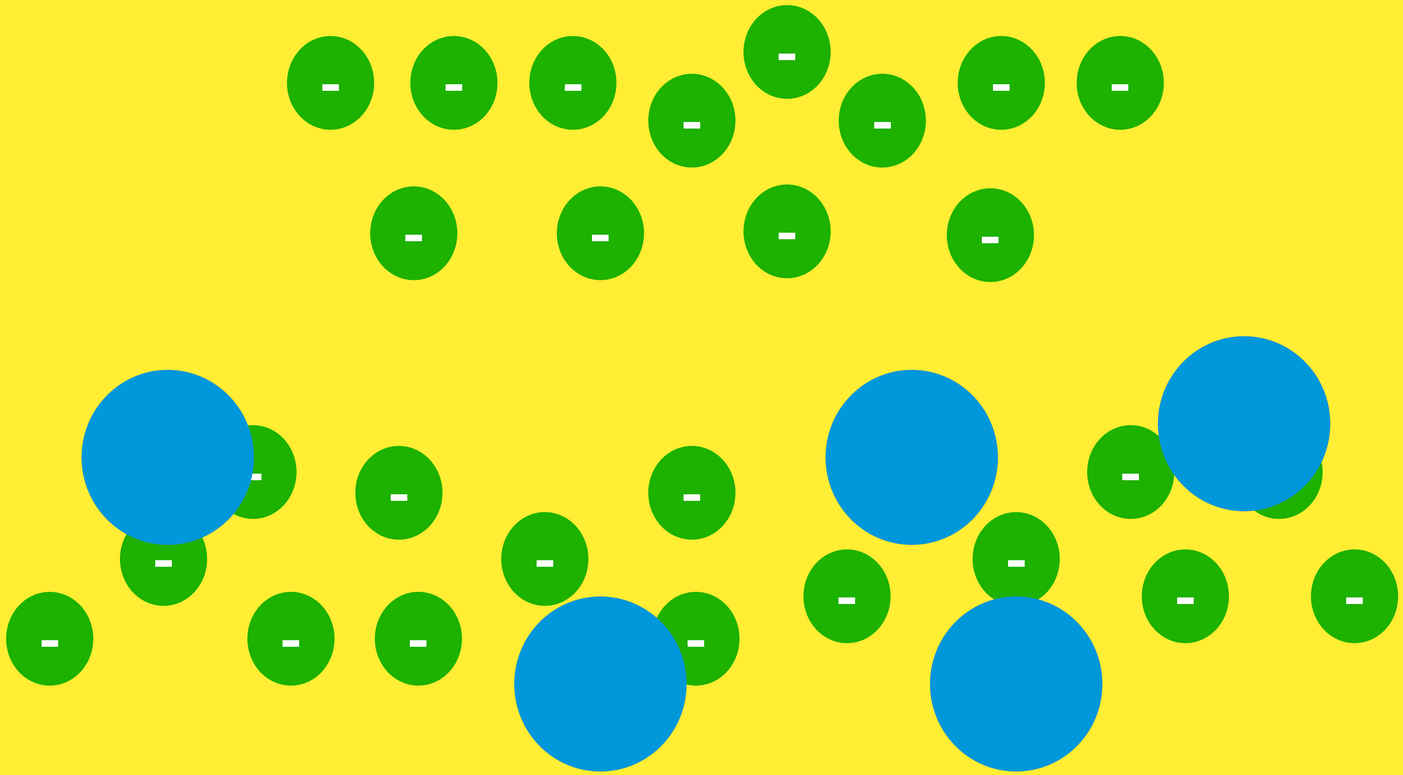


During the day

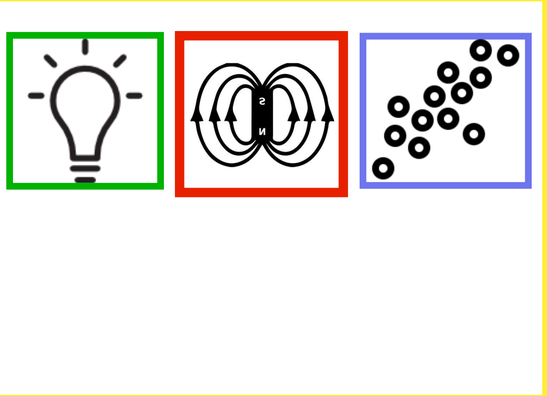




Extra ionisation due to a solar event

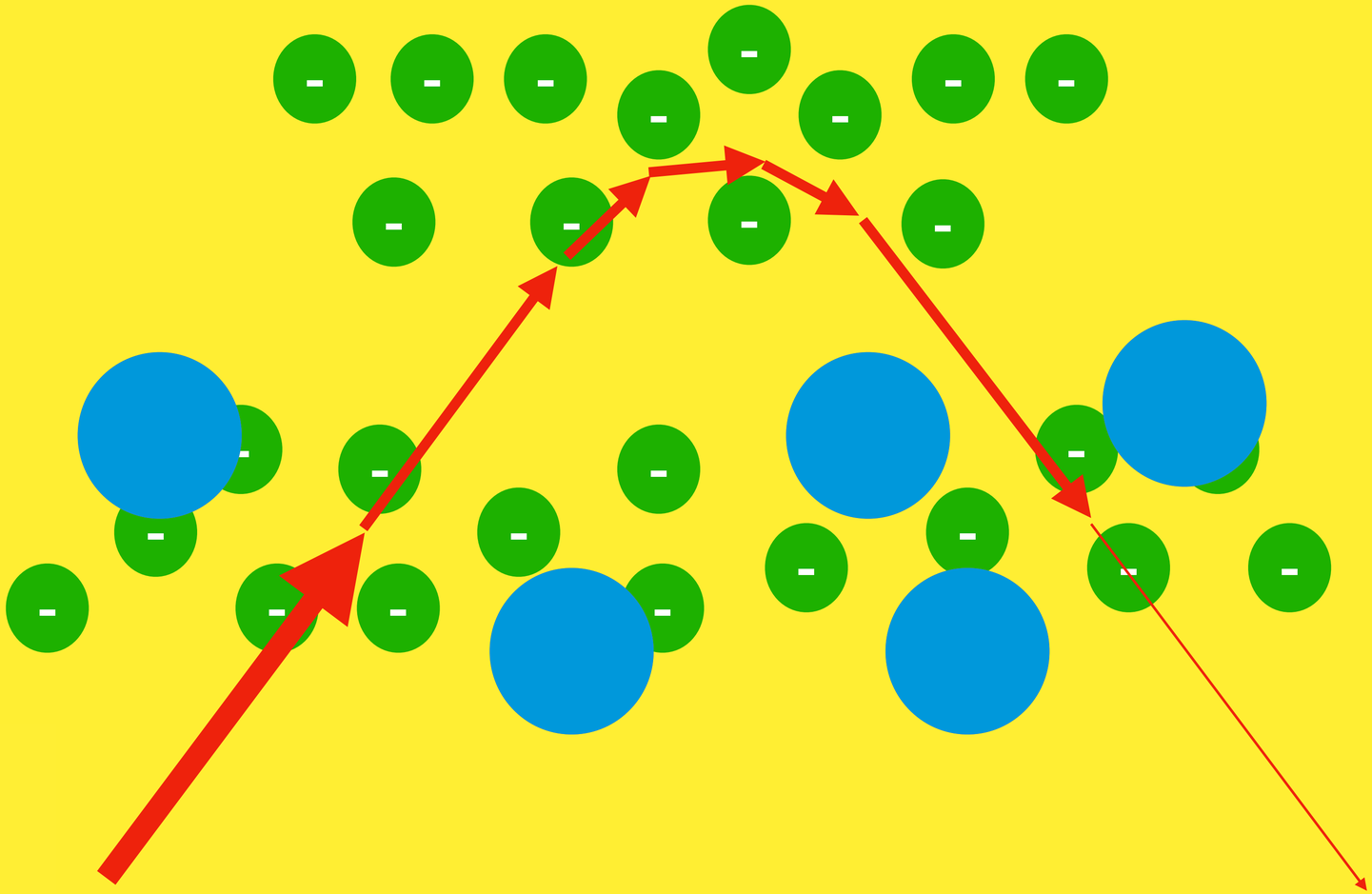




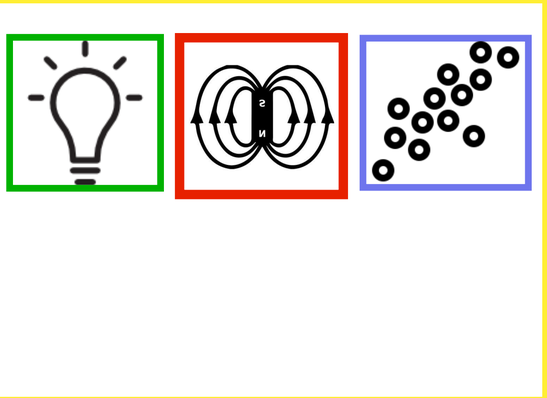




Extra ionisation due to a solar event

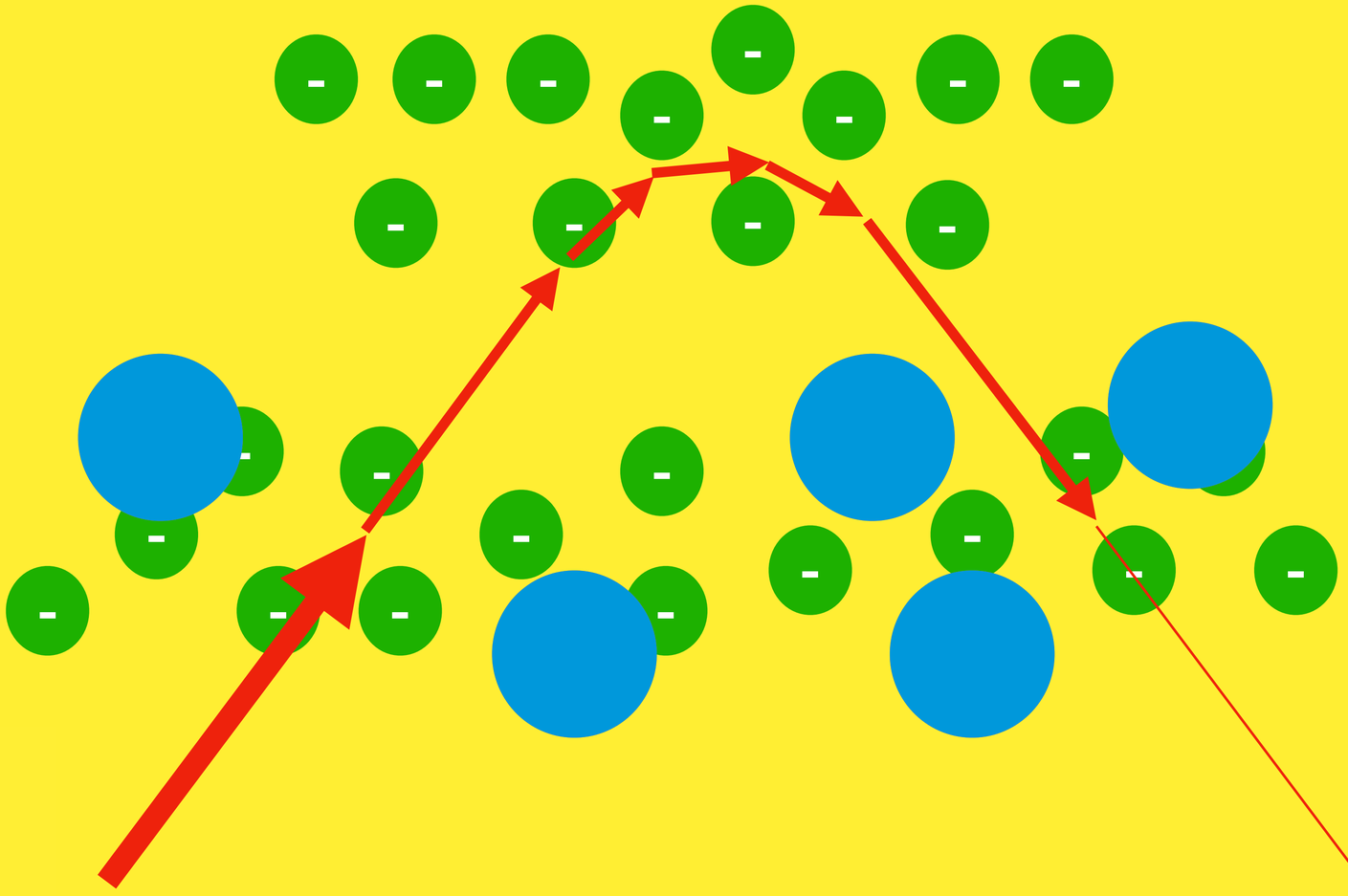




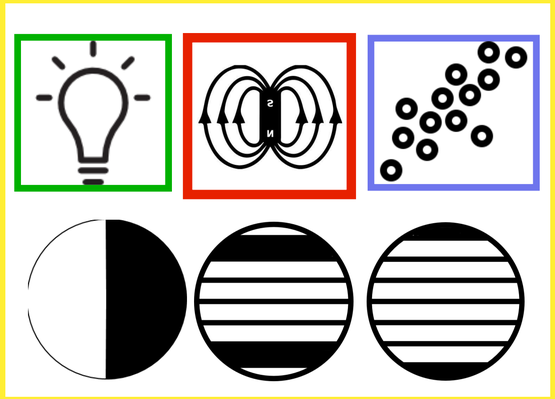




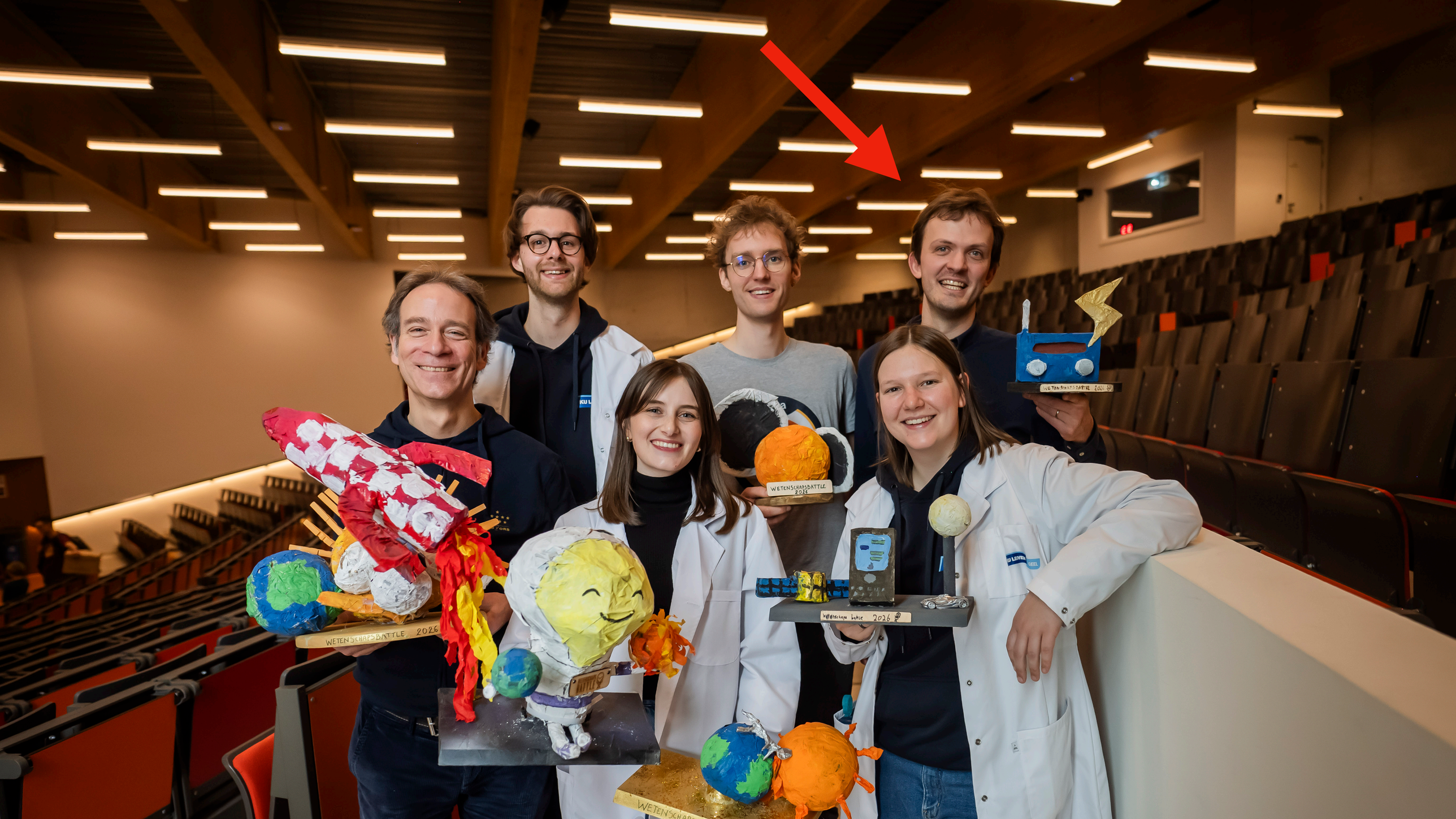
Extra ionisation due to a solar event









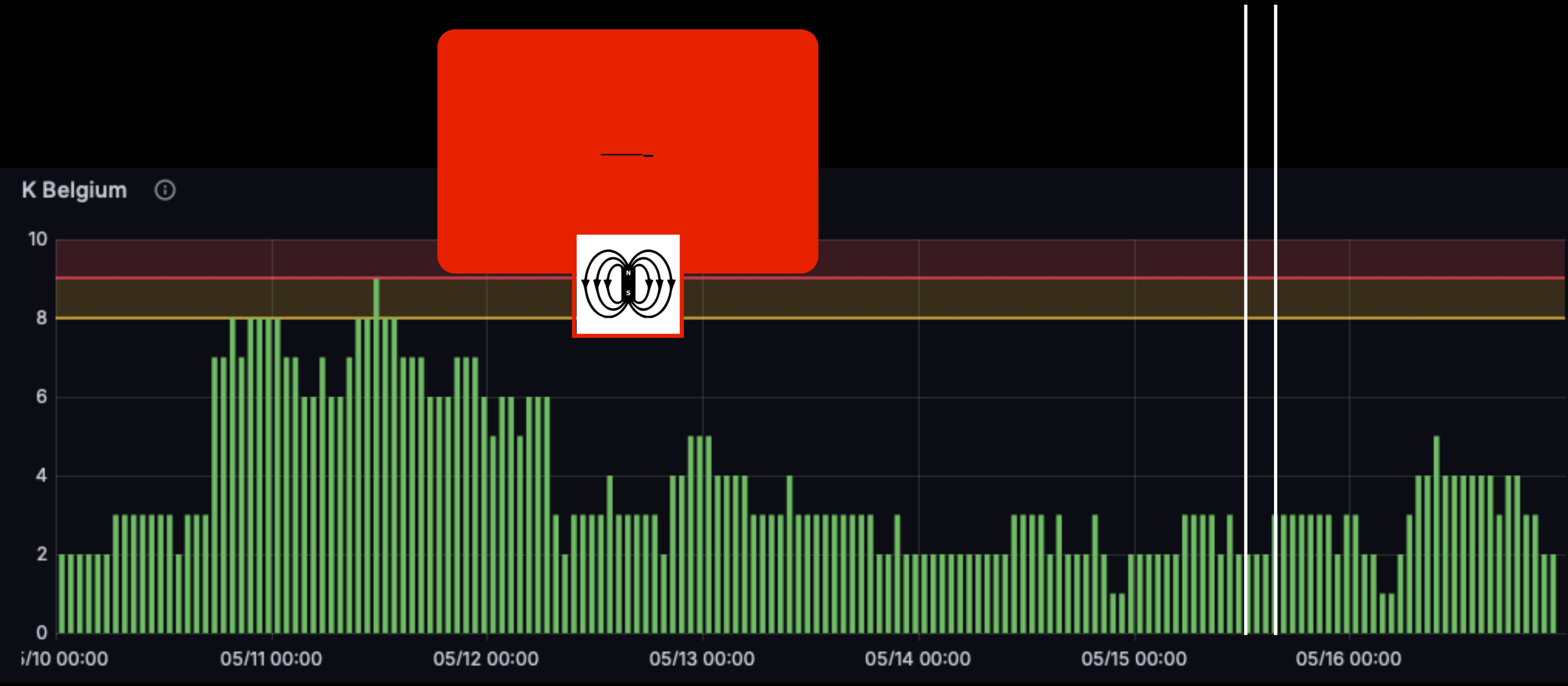

WETENSCHAPSBATTLE 2026
WETENSCHAPSBATTLE 2026
WETENSCHAPSBATTLE 2026


NT
BC
Canada
AB
NU
SK
MB
ND
SD
MN
ON
NE
IA
WI
QC
NL
MO
IL
MI
AR
IN
OH
NB
Greenland
Iceland
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Sweden
Belarus
Norway
Poland
Denmark
Austria
United Kingdom
Ireland
France
Spain
Portugal
DEFENSIE

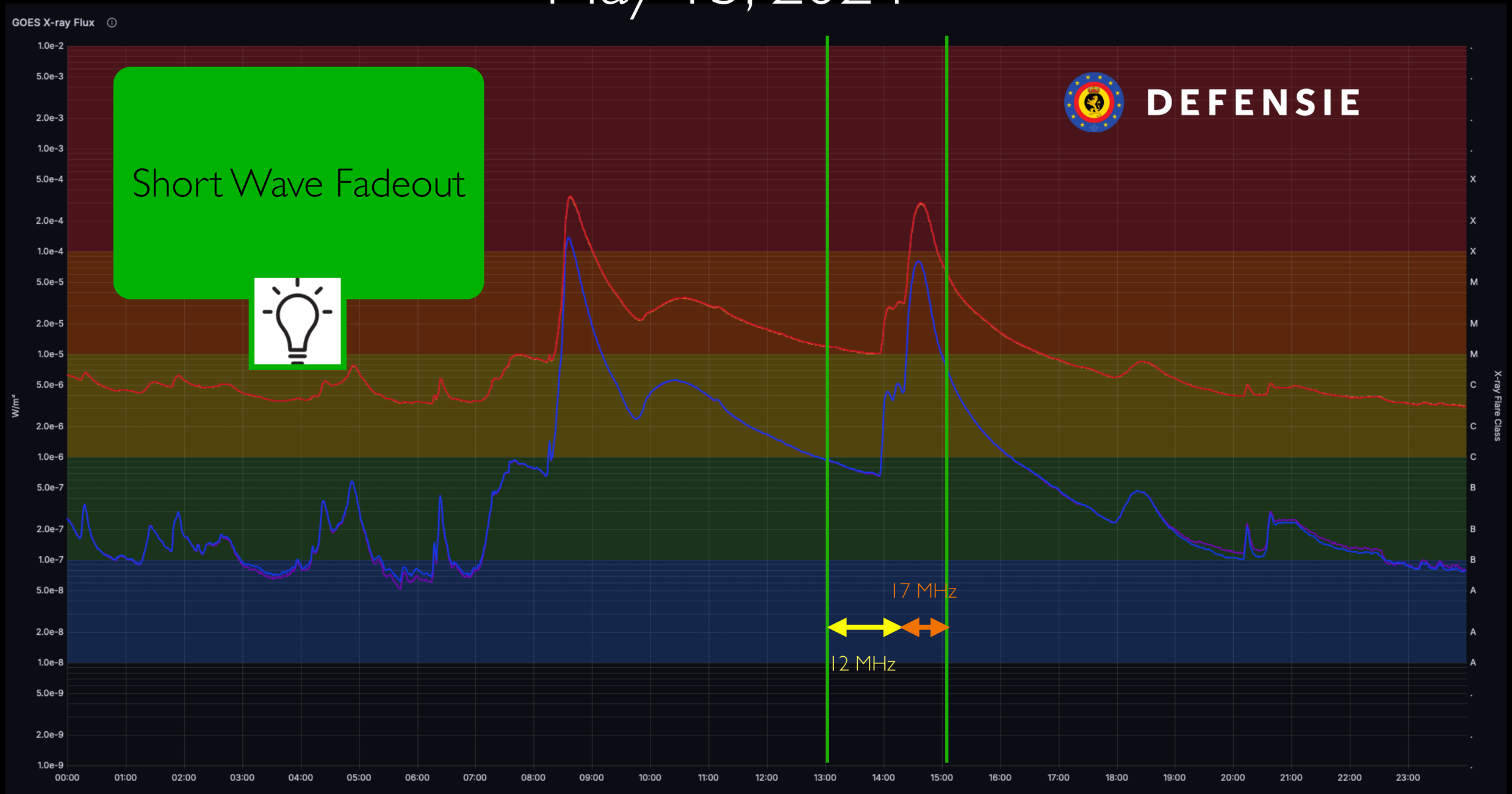
May 15, 2024


17 MHz
12 MHz
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

May 15, 2024


K Belgium
10
8
6
4
2
0
/10 00:00
05/11 00:00
05/12 00:00
05/13 00:00
05/14 00:00
05/15 00:00
05/16 00:00

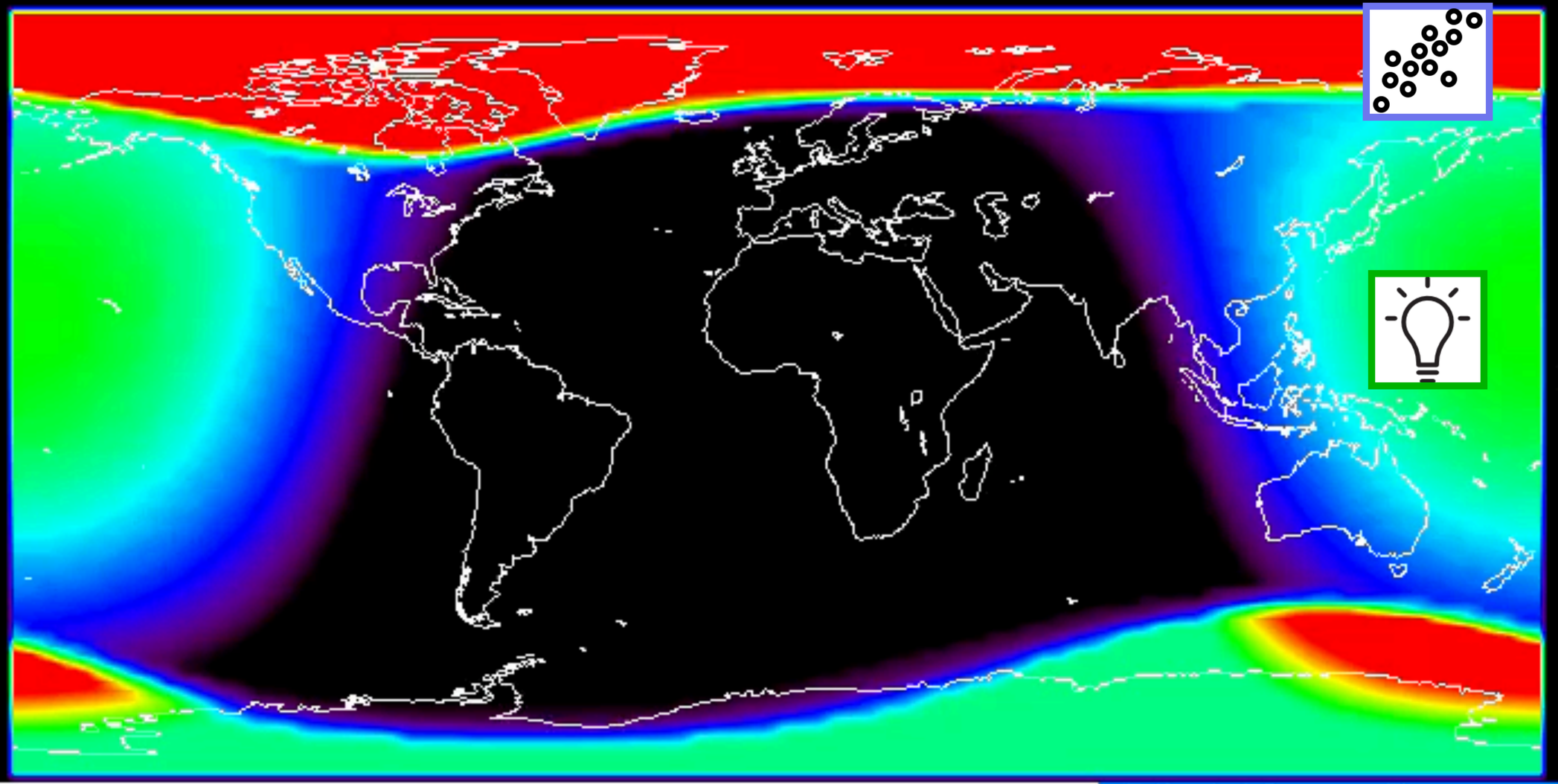
May 15, 2024

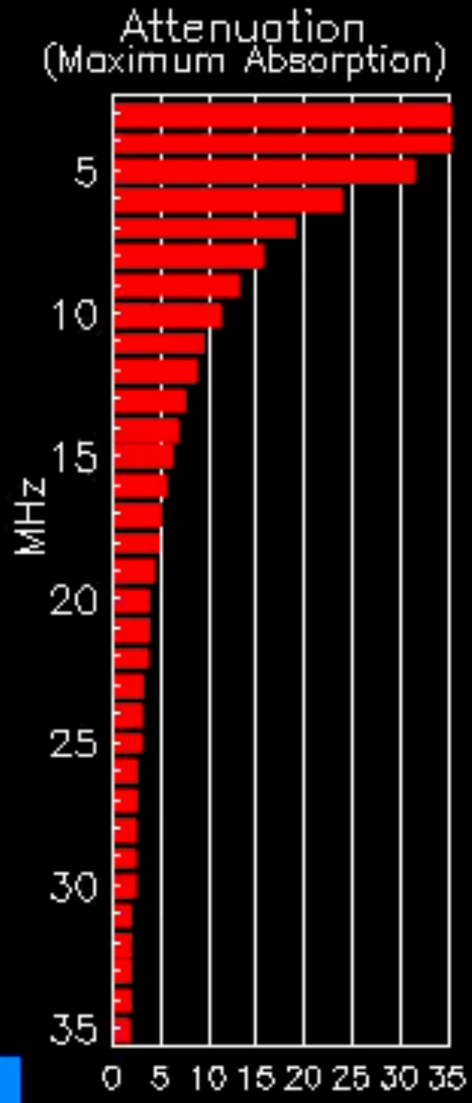

GOES X-ray Flux
Short Wave Fadeout
DEFENSIE
17 MHz
12 MHz
W/m²
X-ray Flare Class
1.0e-2
5.0e-3
2.0e-3
1.0e-3
5.0e-4
2.0e-4
1.0e-4
5.0e-5
2.0e-5
1.0e-5
5.0e-6
2.0e-6
1.0e-6
5.0e-7
2.0e-7
1.0e-7
5.0e-8
2.0e-8
1.0e-8
5.0e-9
2.0e-9
1.0e-9
X
X
X
M
M
M
C
C
C
B
B
B
A
A
A
00:00
01:00
02:00
03:00
04:00
05:00
06:00
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08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

May 15, 2024

Polar Cap Absorption







Highest Frequency Affected by 1dB Absorption

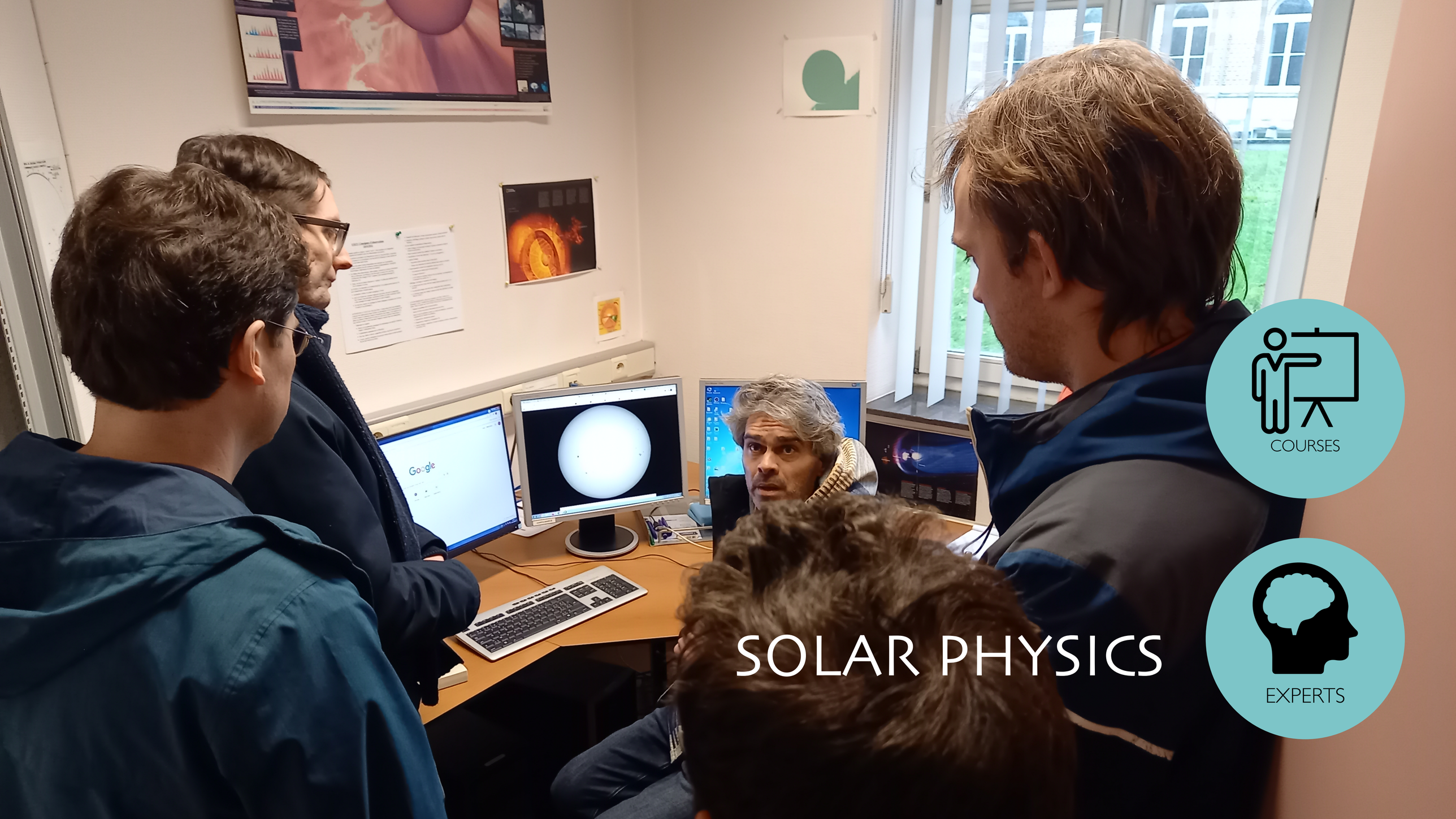
0 5 10 15 20 25 30 35

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

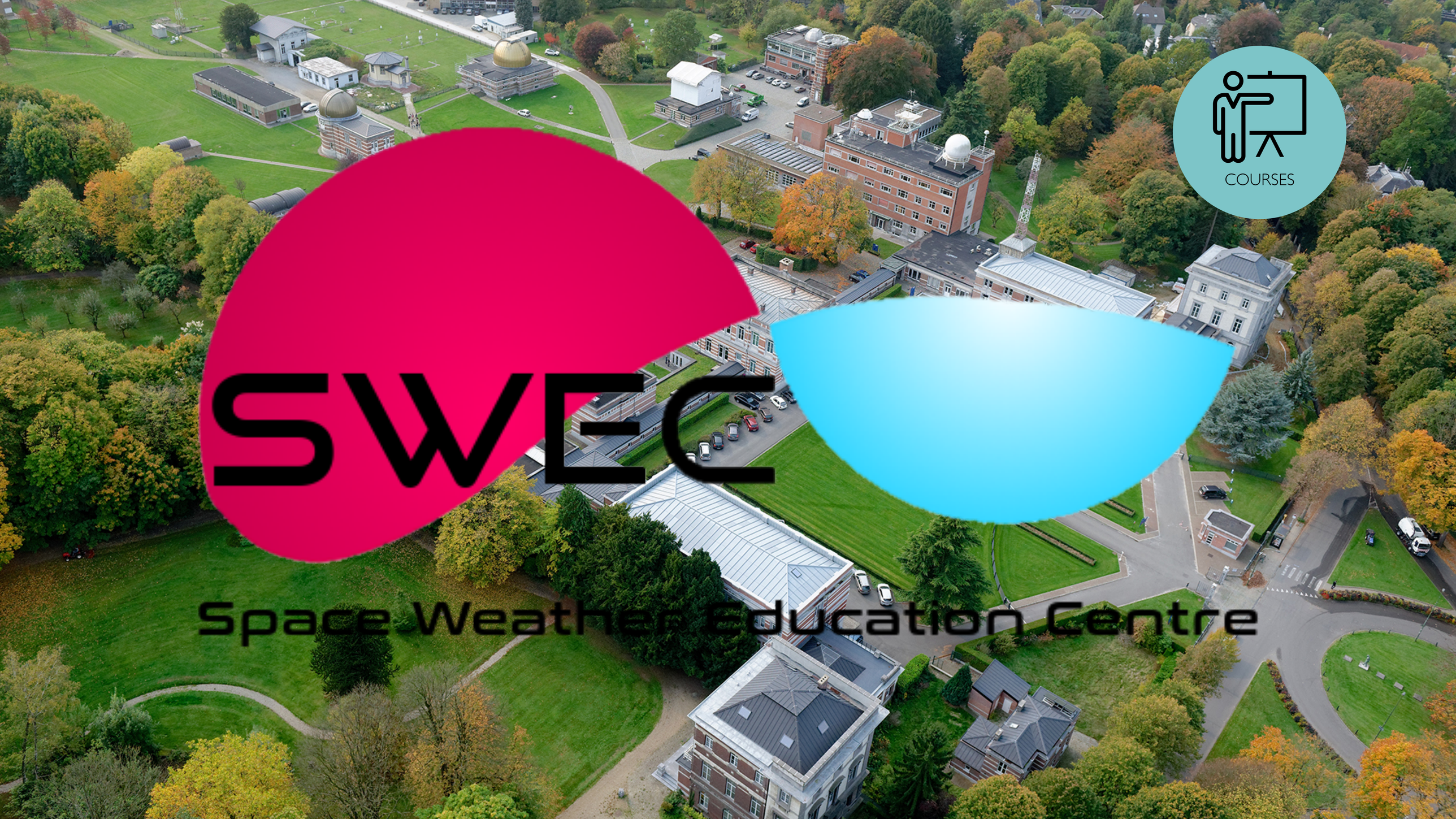
Minor Proton Flux
NOAA/SWPC Boulder, CO USA



SOLAR PHYSICS

COURSES

EXPERTS

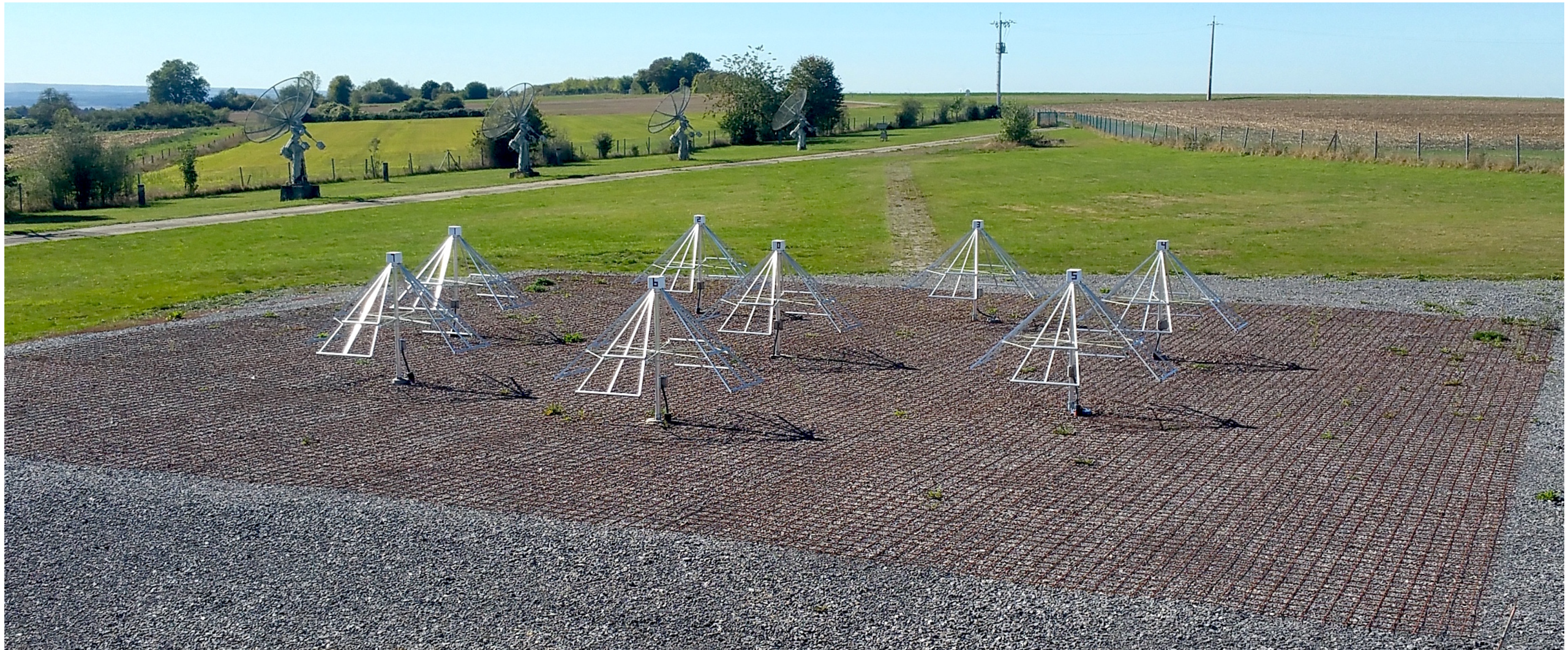

COURSES
SWEC
Space Weather Education Centre


EXPERTS

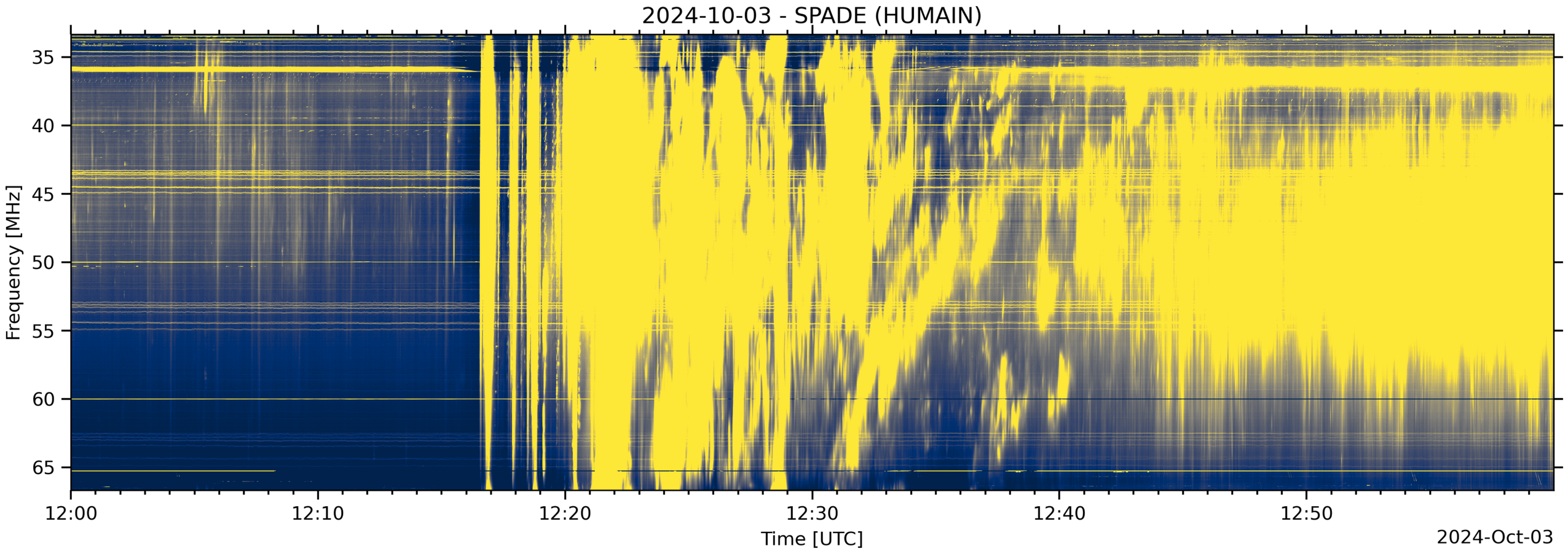
SPADE

- 25 - 75 MHz
- 8 antennas - phased array
- 20 x 20 m square grid
- Solar spectrograph

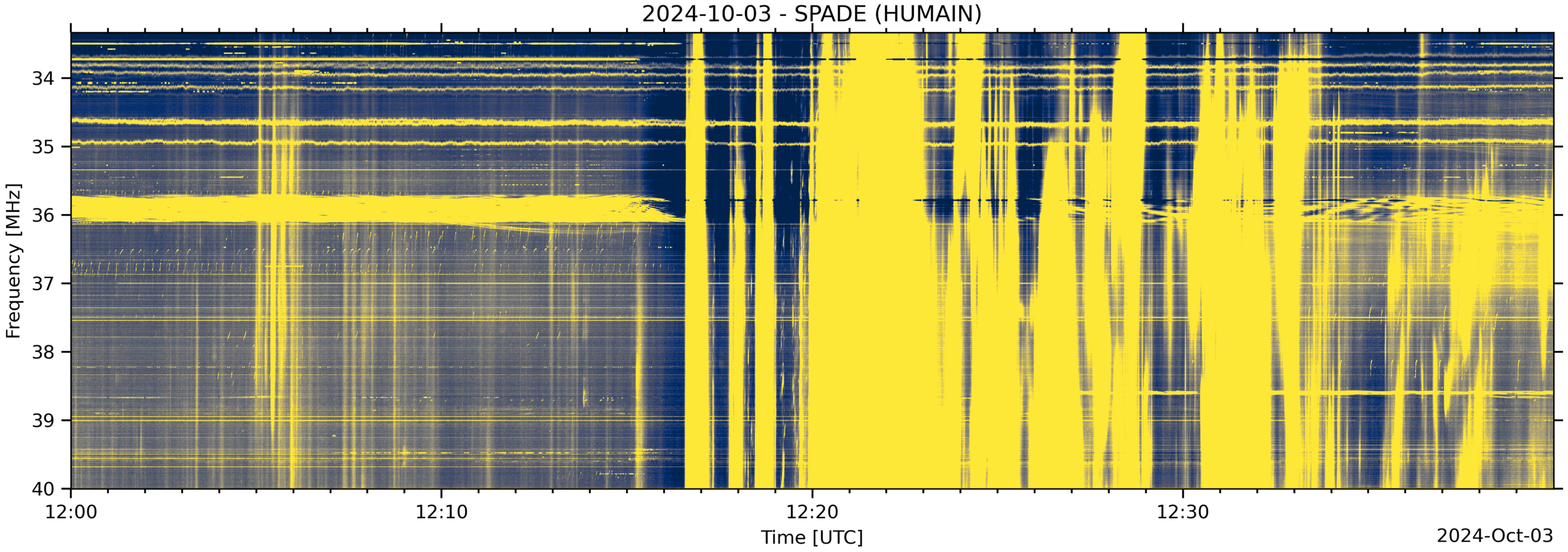
OBSERVATIONS



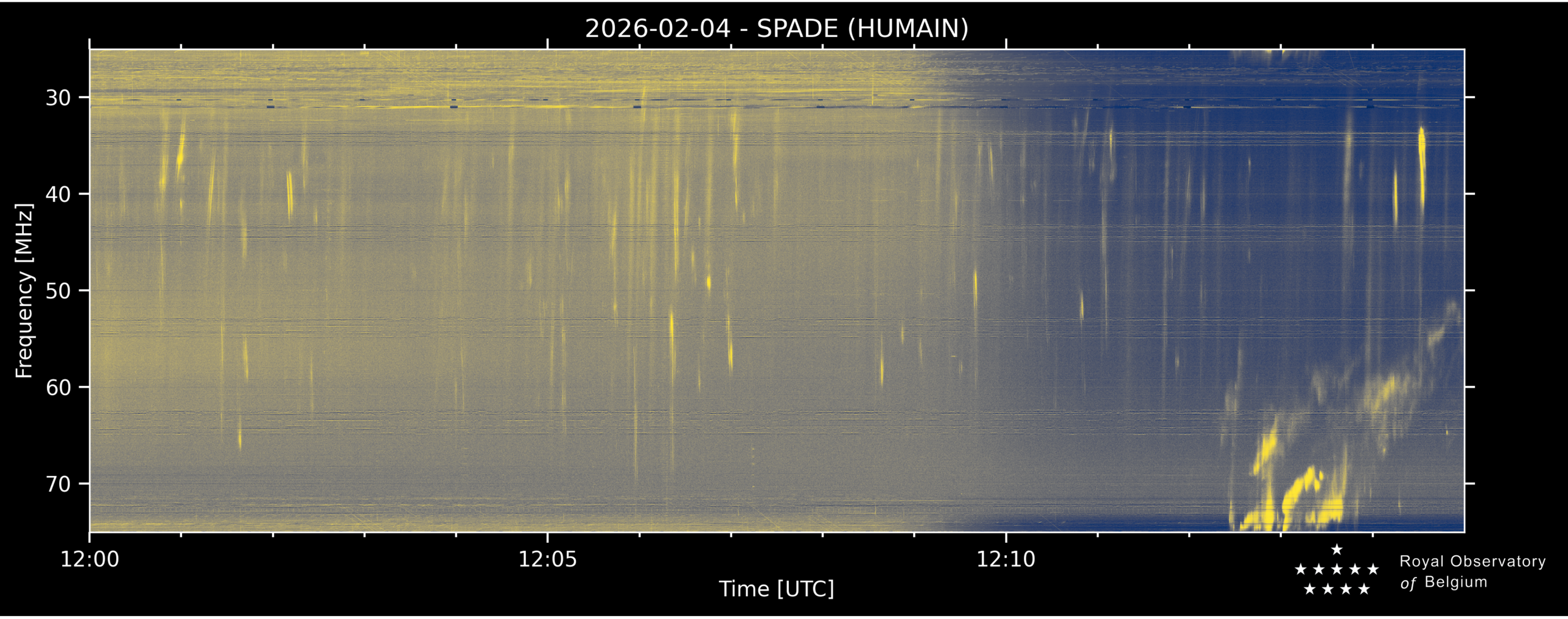
DATA


2024-10-03 - SPADE (HUMAIN)
Frequency [MHz]
35
40
45
50
55
60
65
12:00
12:10
12:20
12:30
12:40
12:50
Time [UTC]
2024-Oct-03


DATA

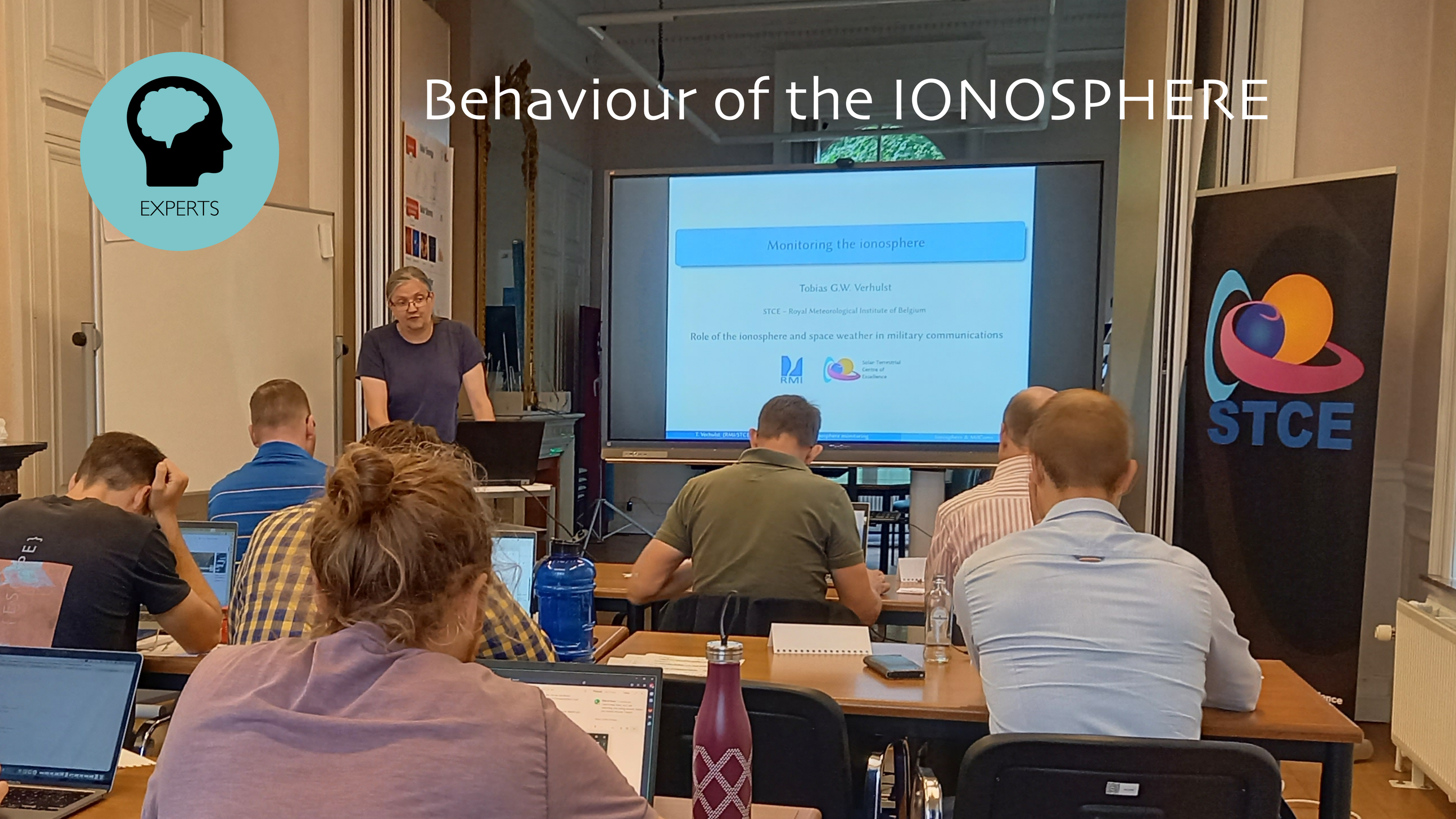

2024-10-03 - SPADE (HUMAIN)
Frequency [MHz]
34
35
36
37
38
39
40
12:00
12:10
12:20
12:30
Time [UTC]
2024-Oct-03

DATA


2026-02-04 - SPADE (HUMAIN)
Frequency [MHz]
30
40
50
60
70
12:00
12:05
12:10
Time [UTC]
Royal Observatory
of Belgium

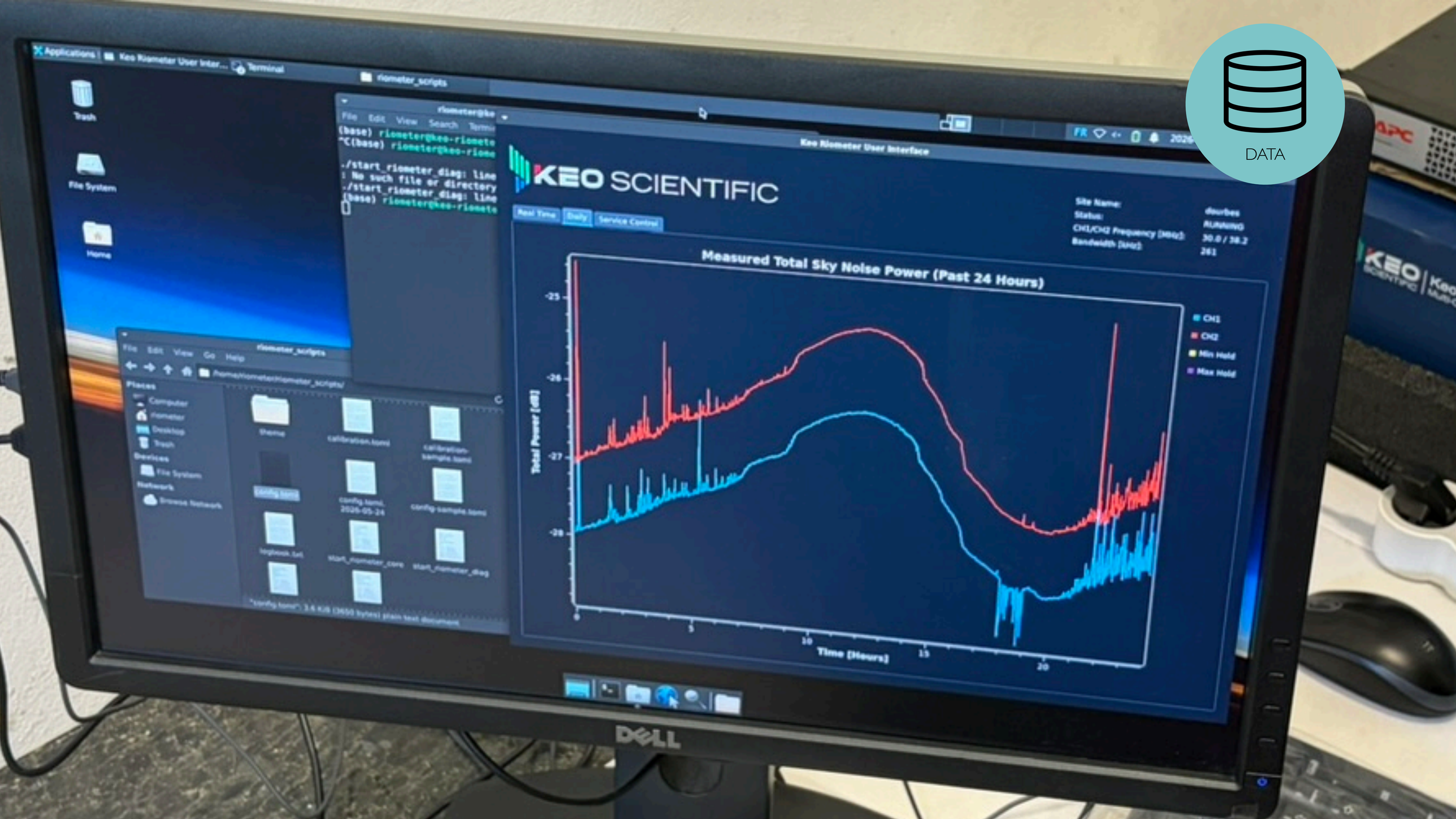
EXPERTS

Behaviour of the IONOSPHERE



OBSERVATIONS



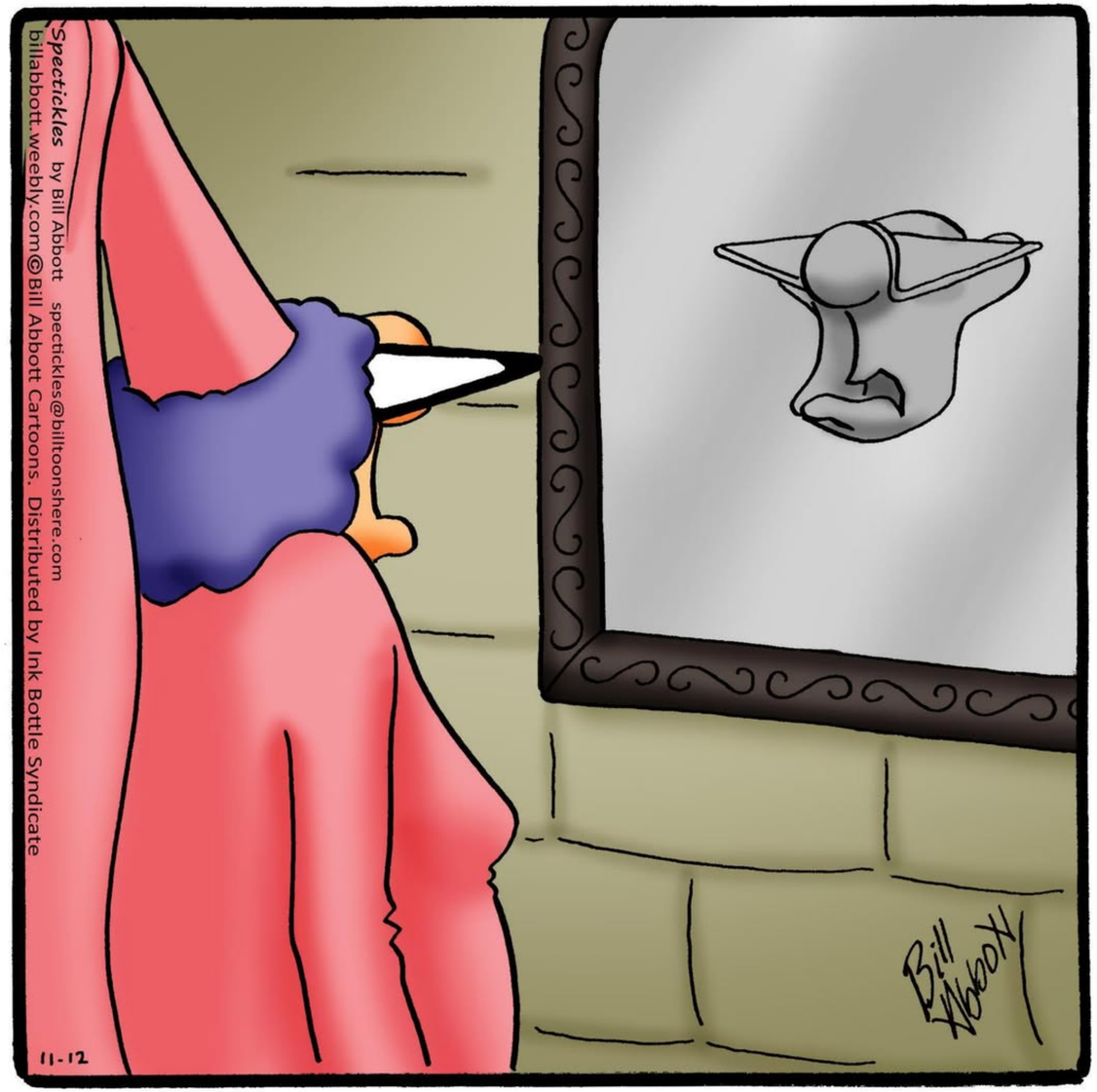

DATA
KEO SCIENTIFIC
Keo Riometer User Interface
Measured Total Sky Noise Power (Past 24 Hours)
Total Power [dB]
Time [Hours]
CH1
CH2
Min Hold
Max Hold
Site Name:
Status:
CH1/CH2 Frequency [MHz]:
Bandwidth [kHz]:
dourbes
RUNNING
30.0 / 38.2
261
Real Time
Daily
Service Control
riometer_scripts
DELL



Impact: decrease of MUF

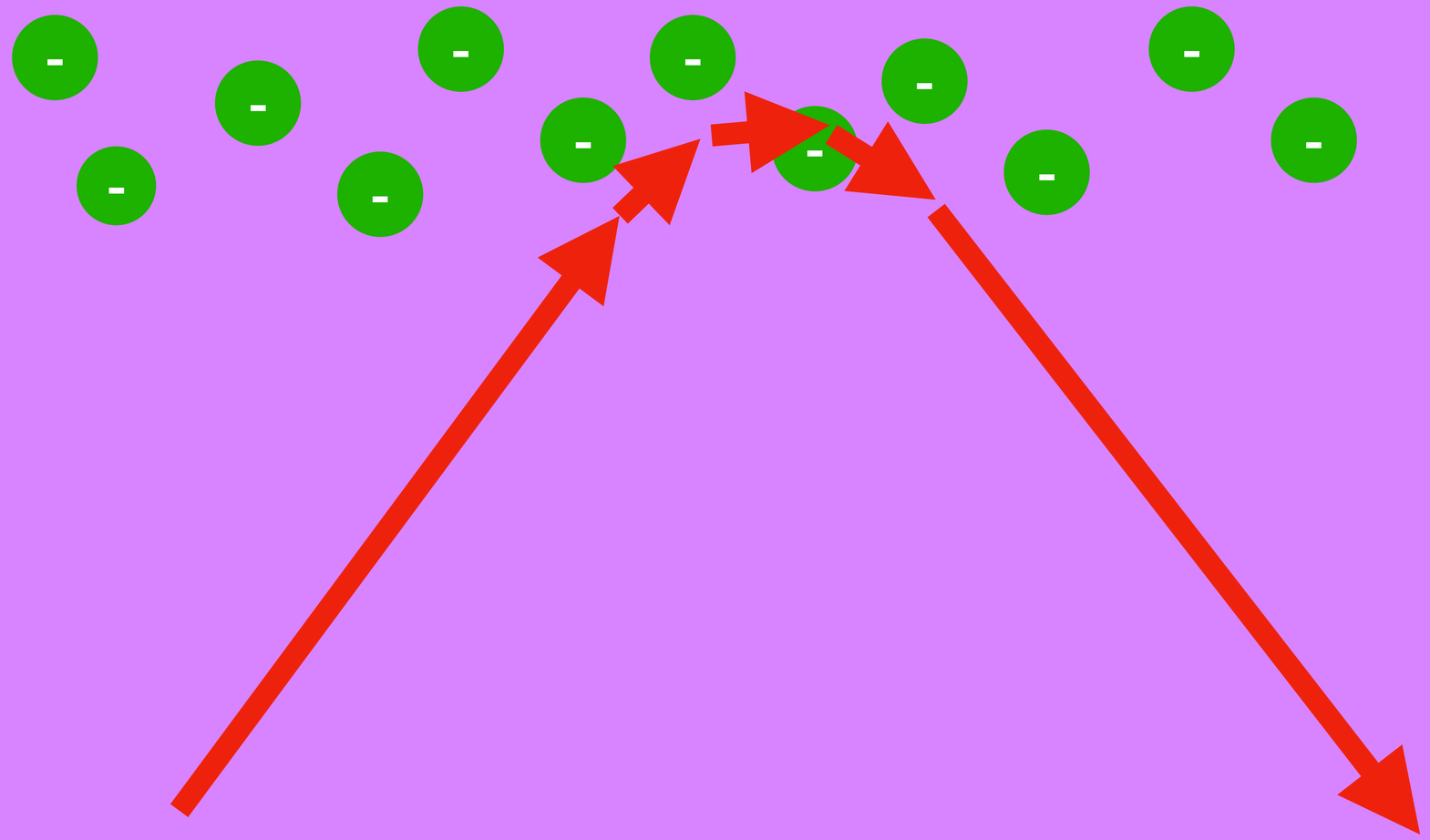
Post storm depression



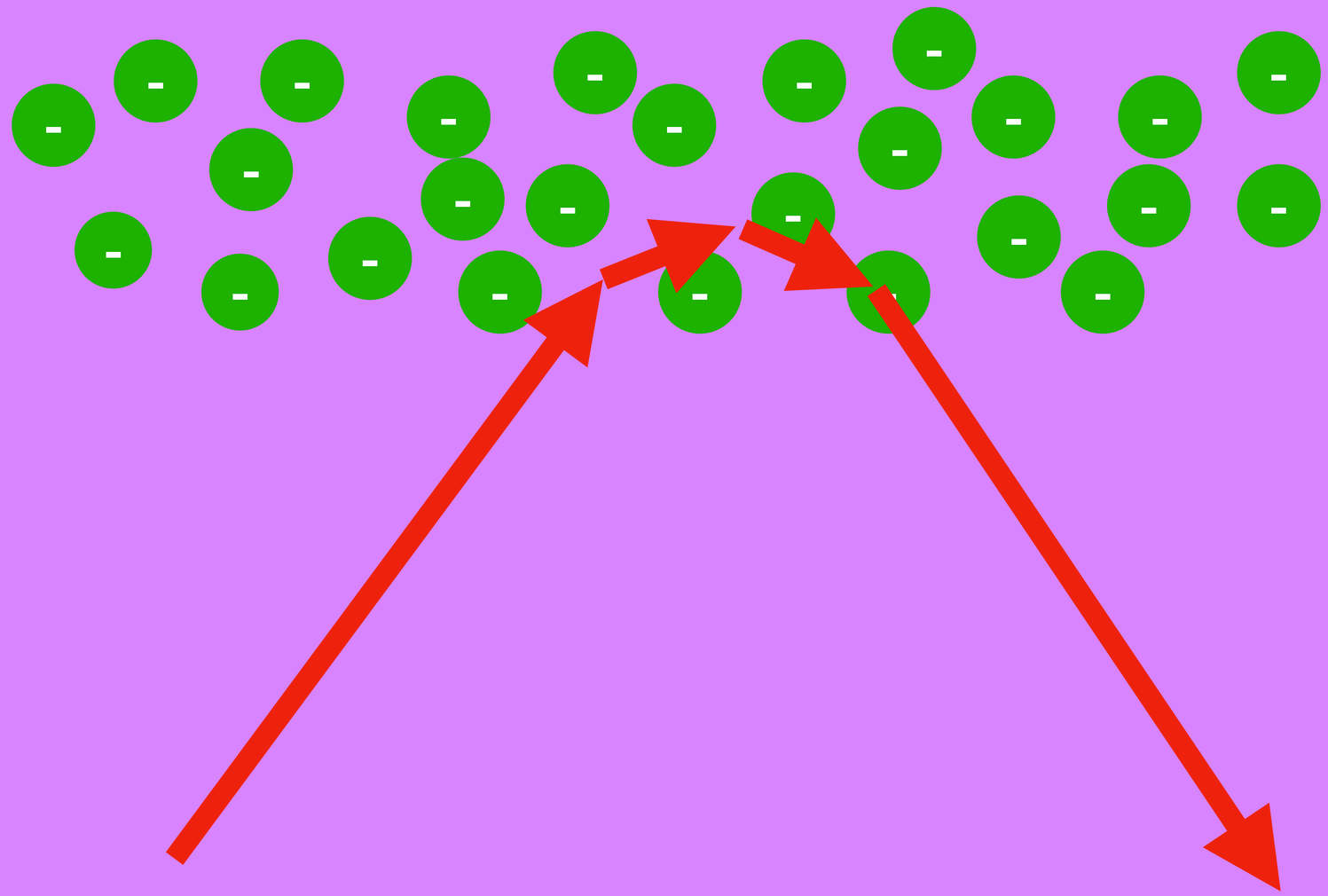


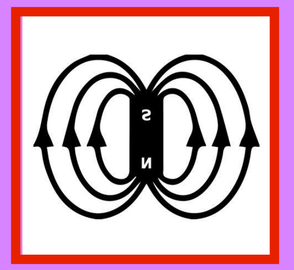
“Before I answer that, may I remind you that it’s seven years of bad luck to break a mirror?”

Reflection of HF waves - MUF



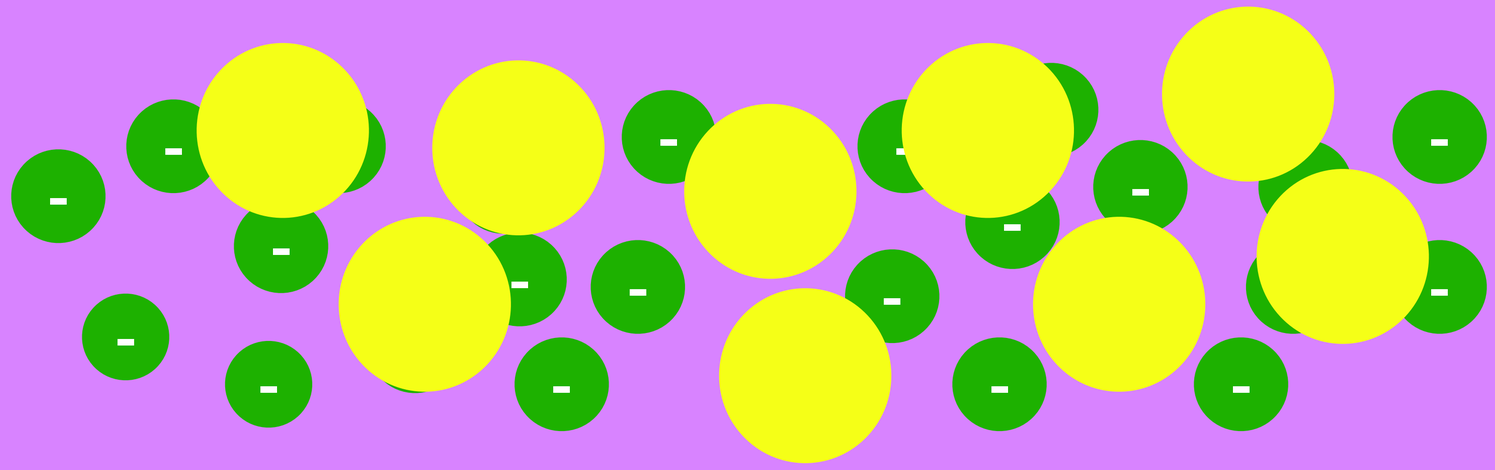
First phase: better reflection

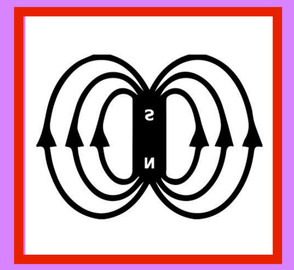






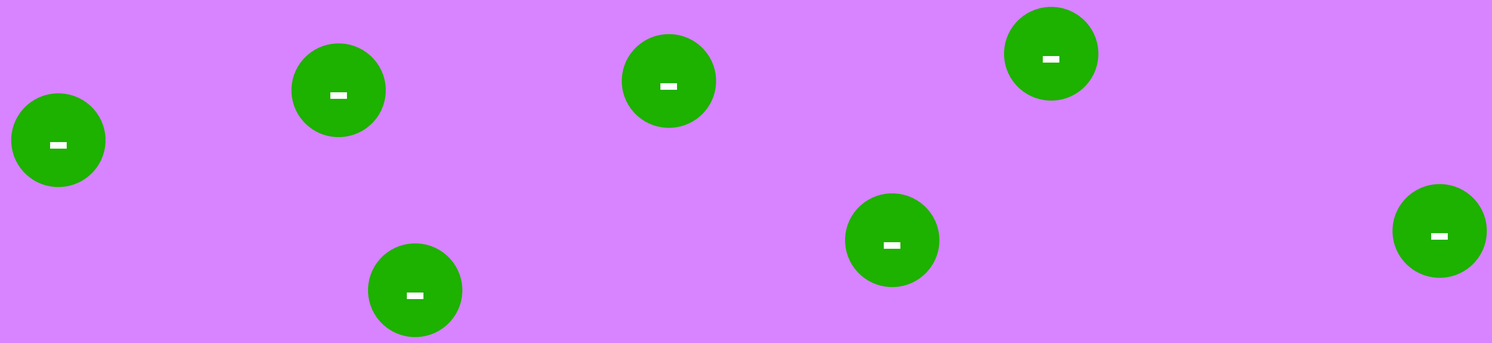
Second phase: Slower neutrals arrive

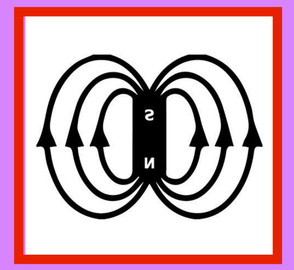






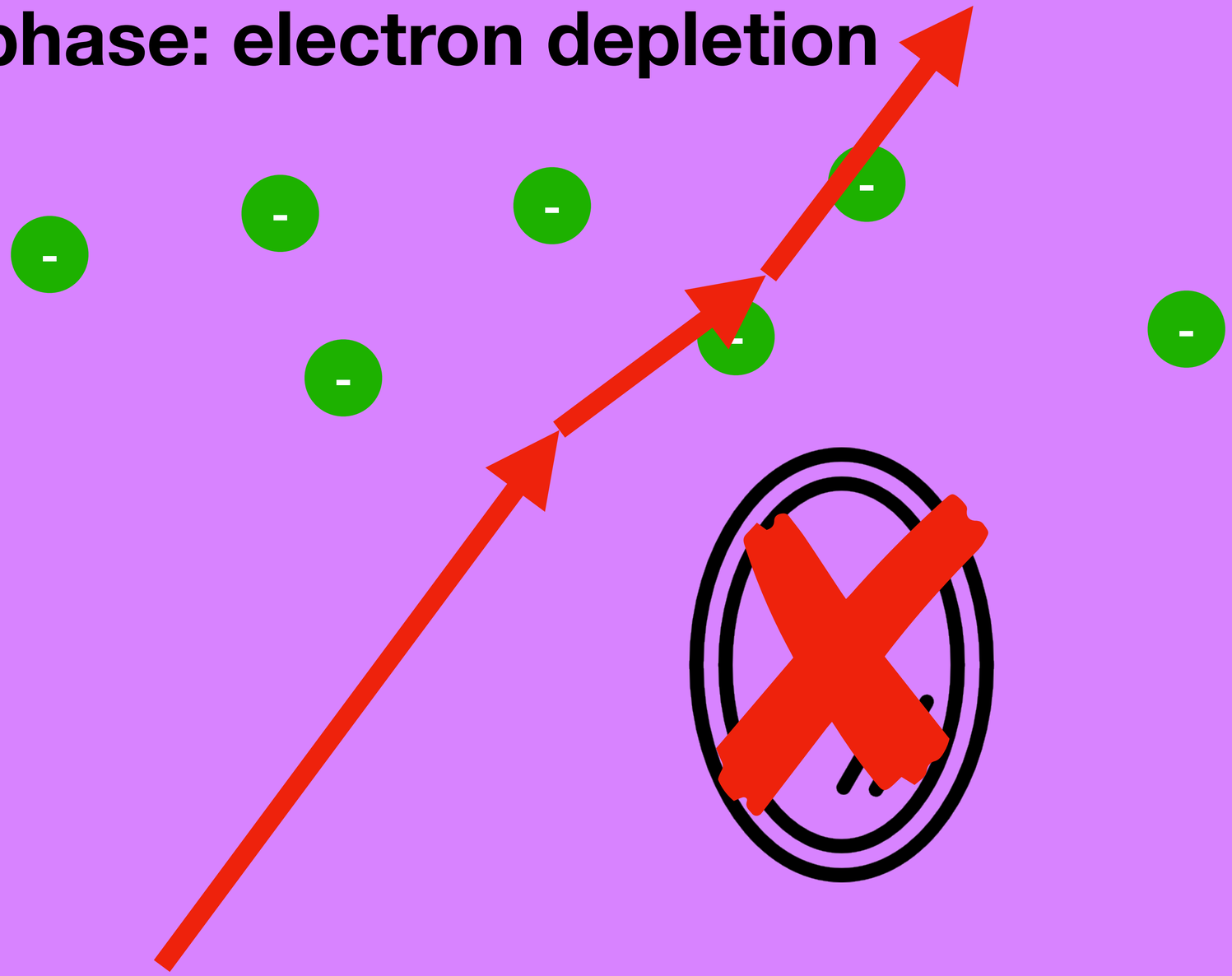
Second phase: electron depletion

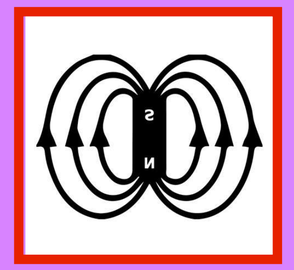






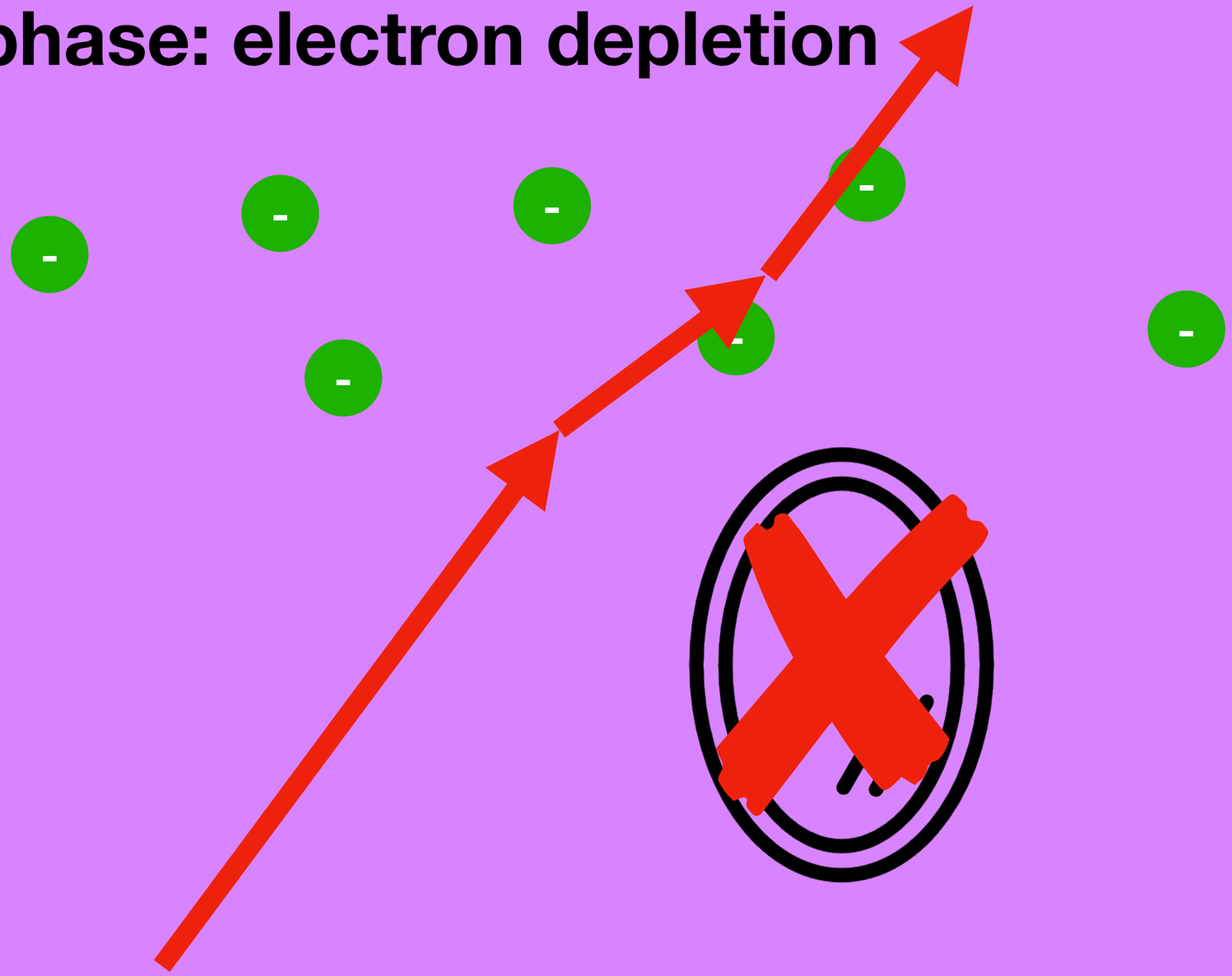
Second phase: electron depletion

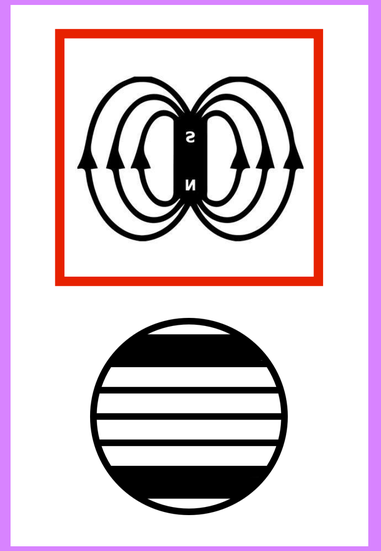






Second phase: electron depletion



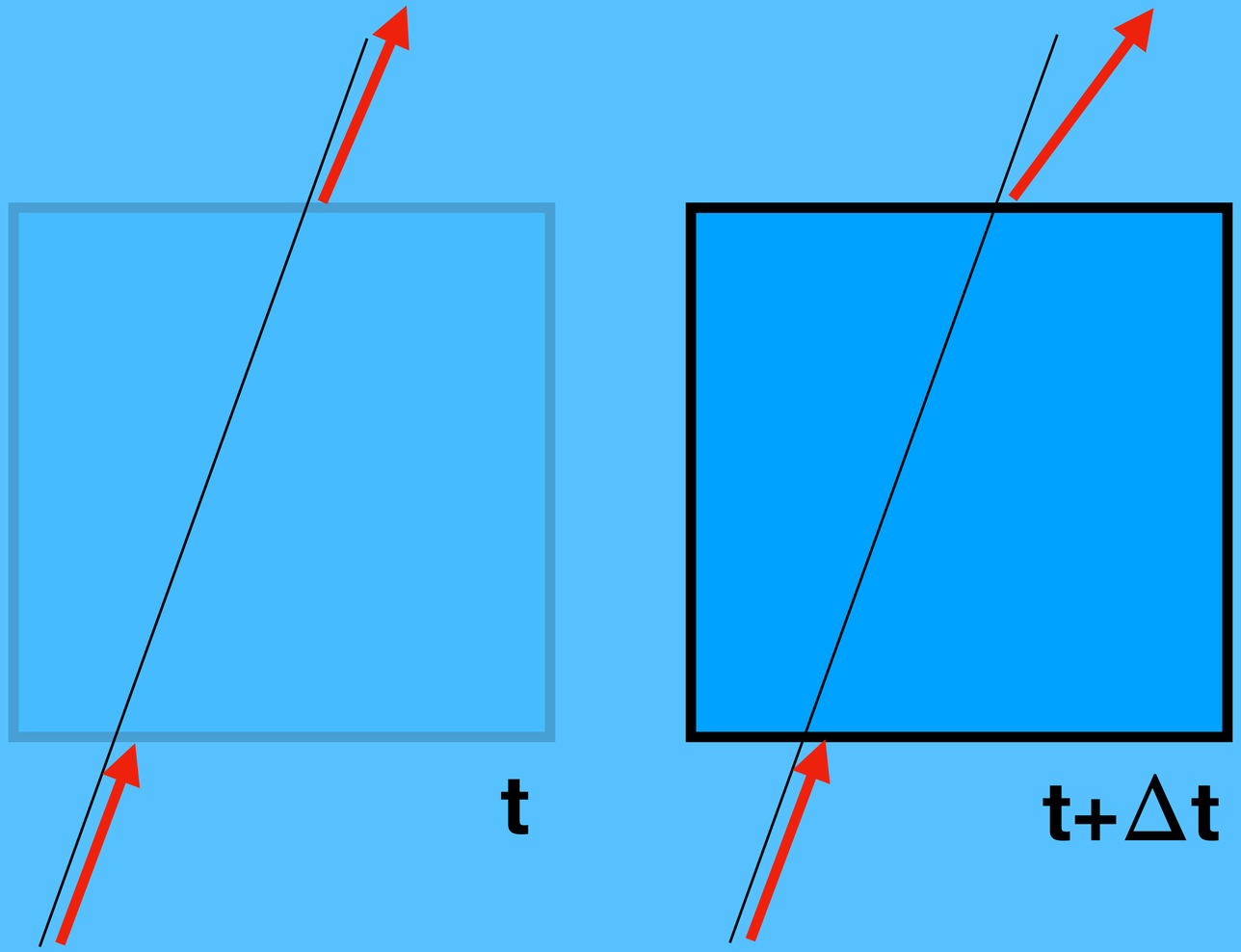






Impact: Delay



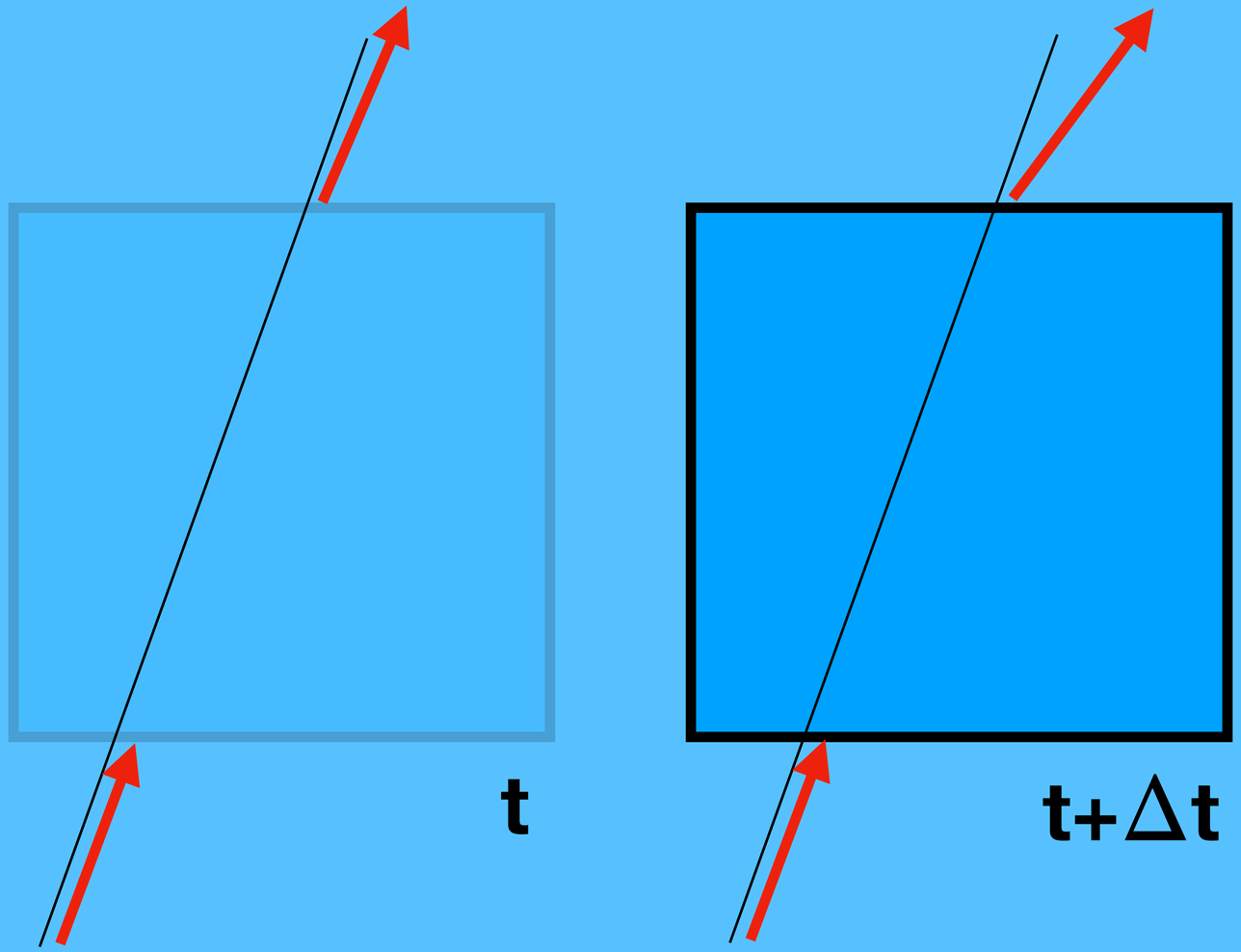




Impact: Delay



VTEC

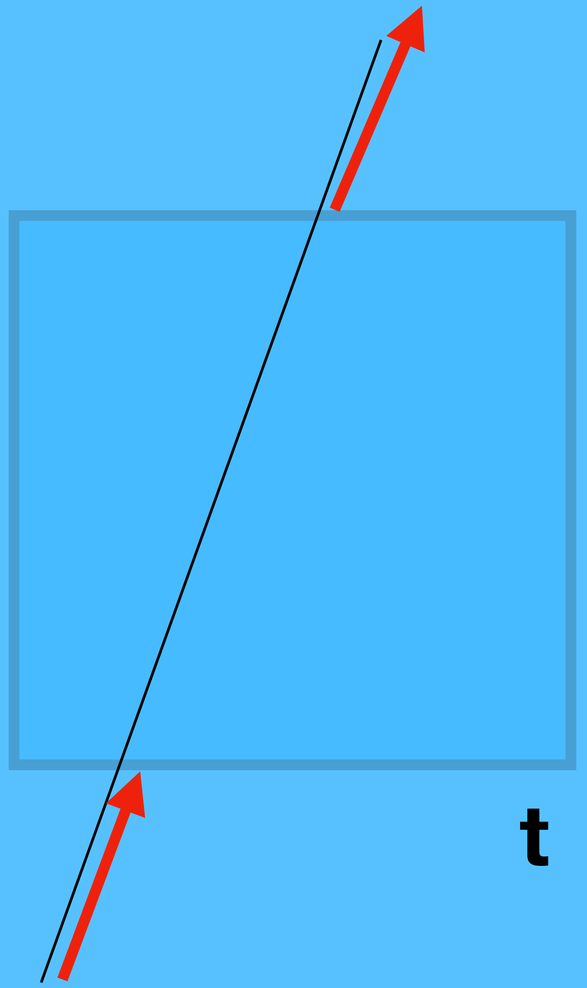




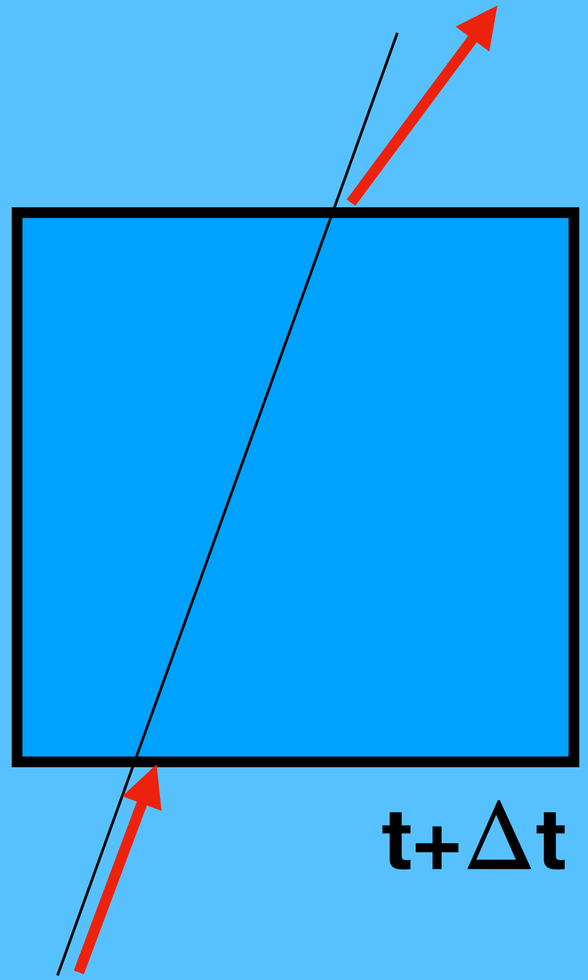
Impact: Delay



VTEC



t



t+Δt

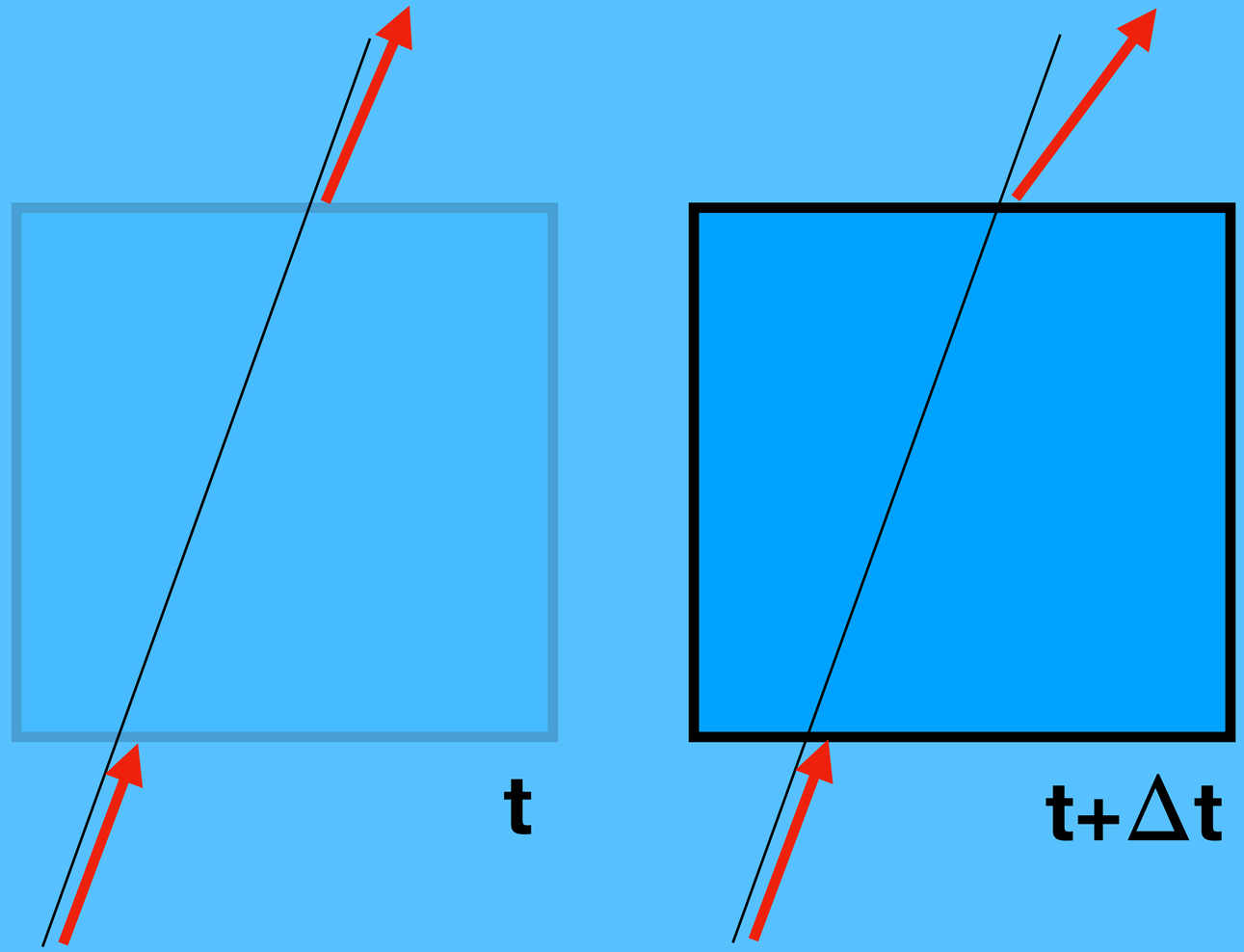


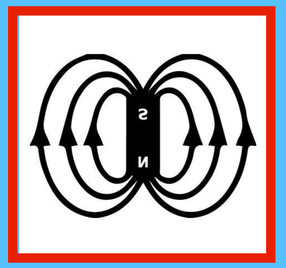


Impact: Delay



VTEC









Impact

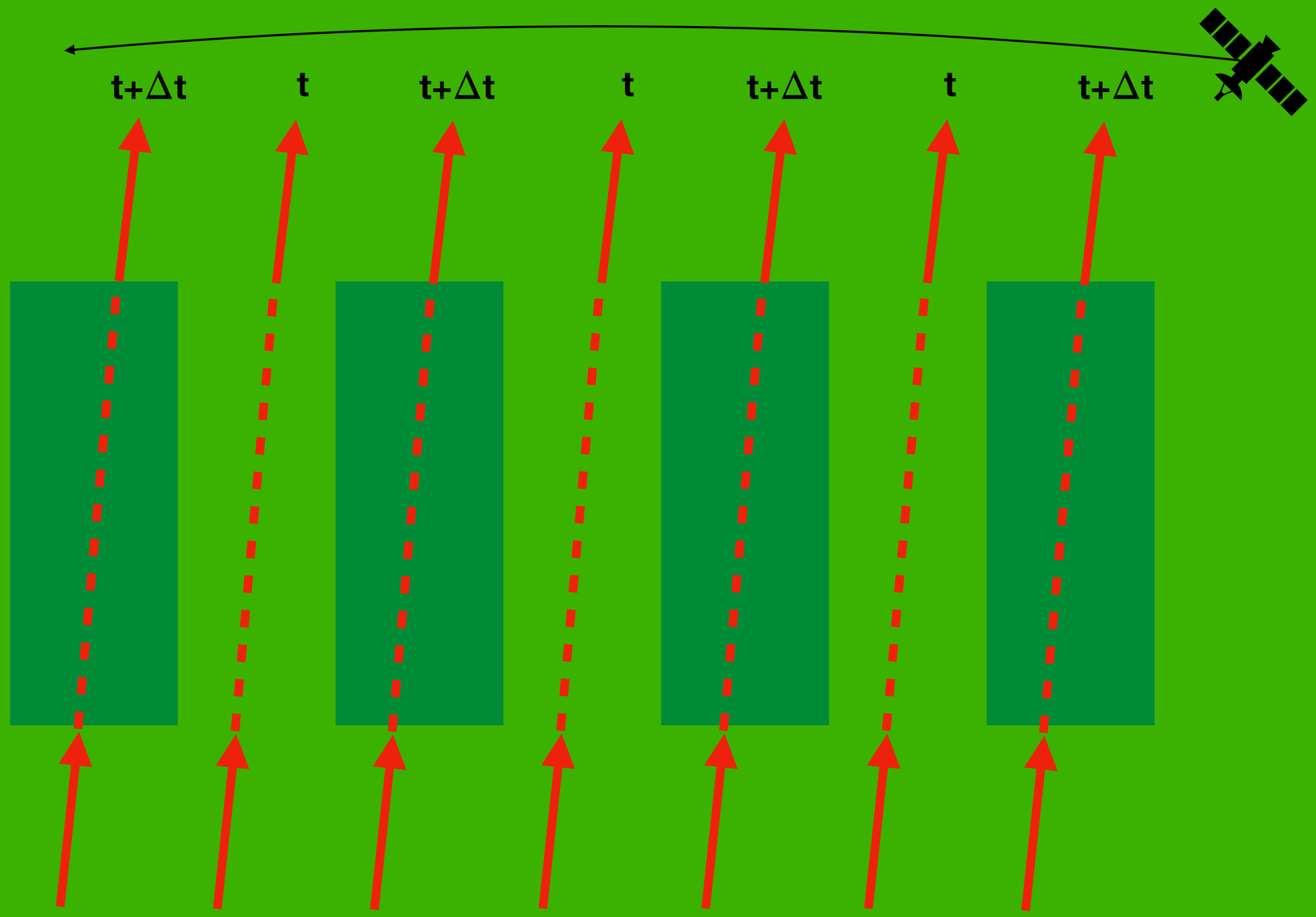
Scintillation

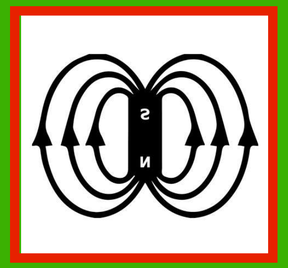




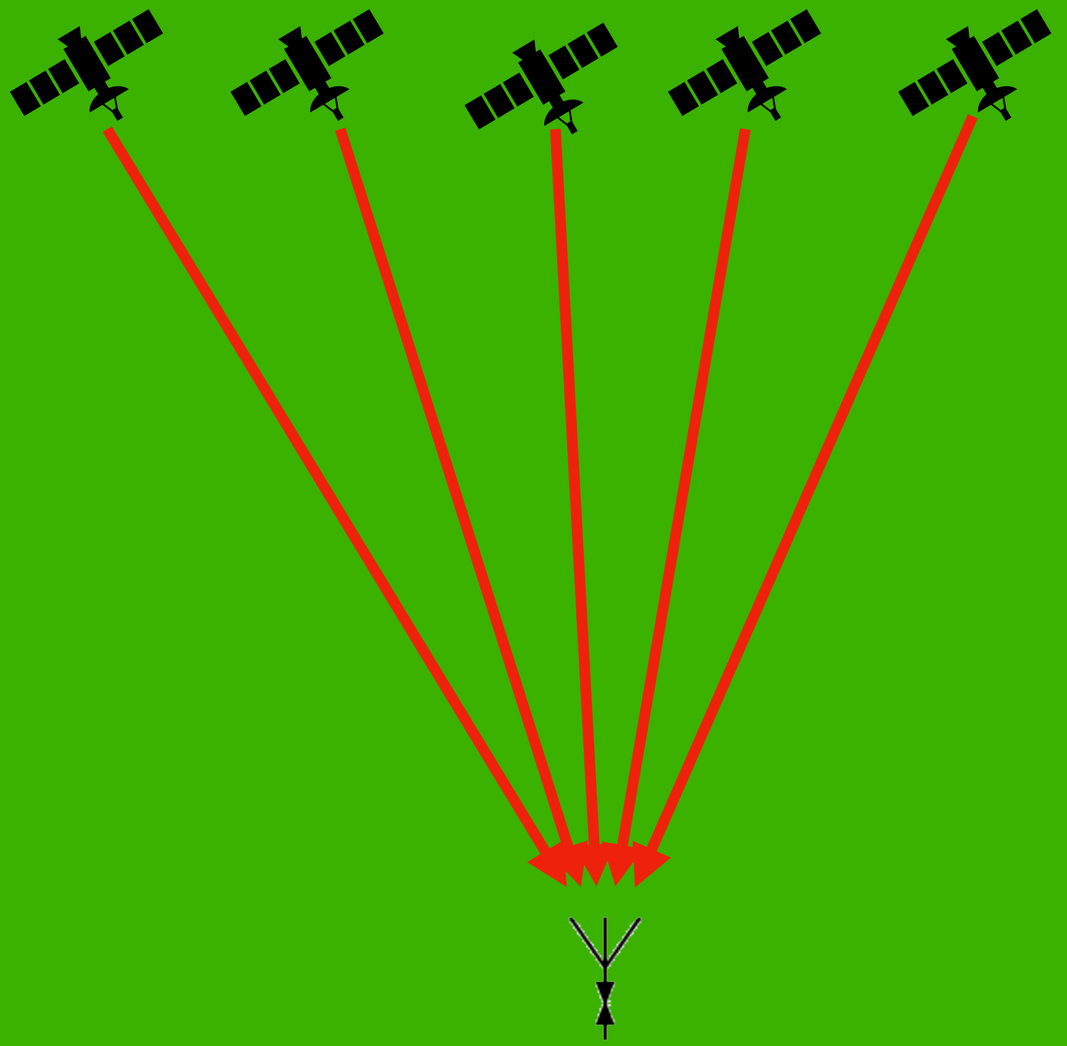


Small scale irregularities

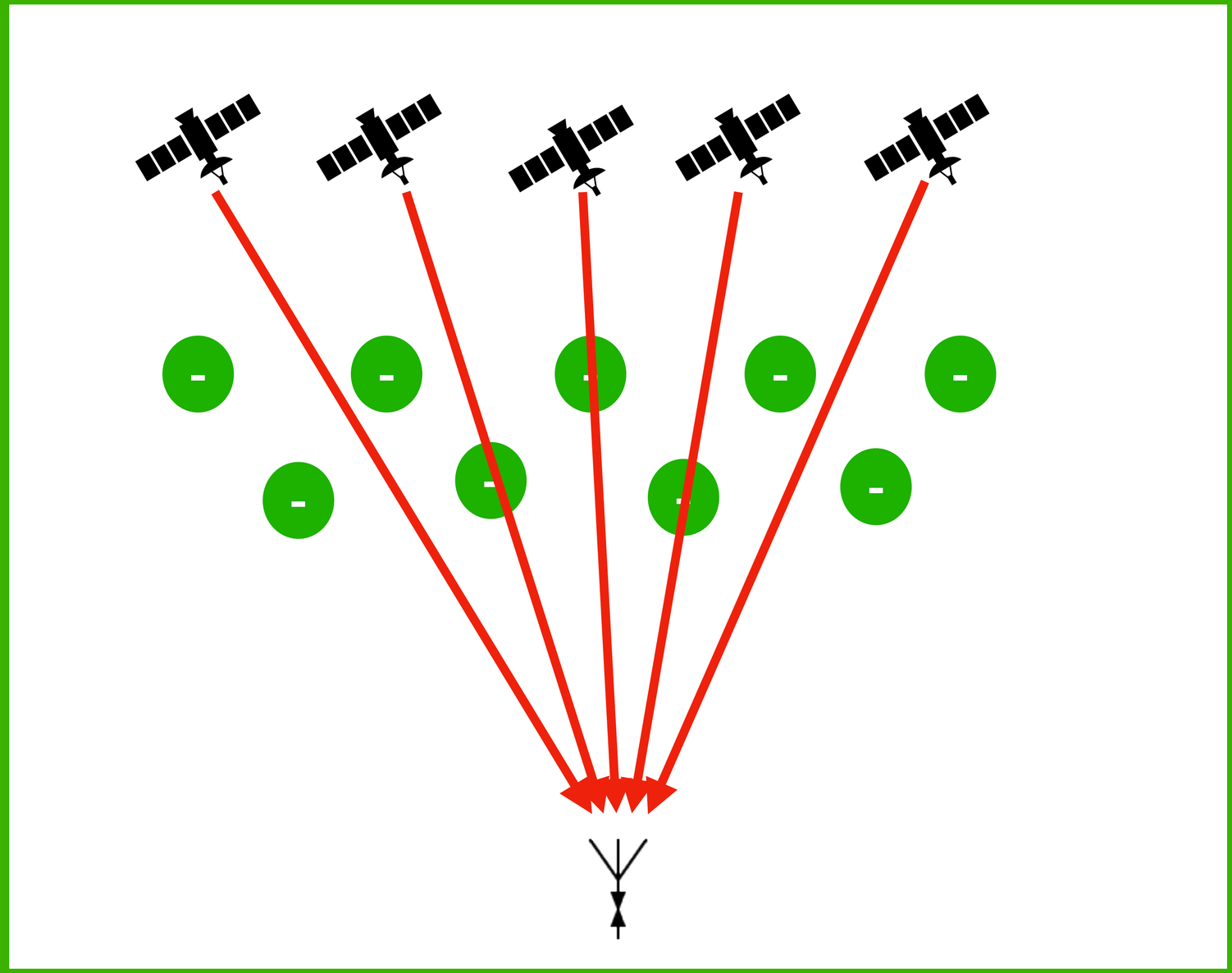






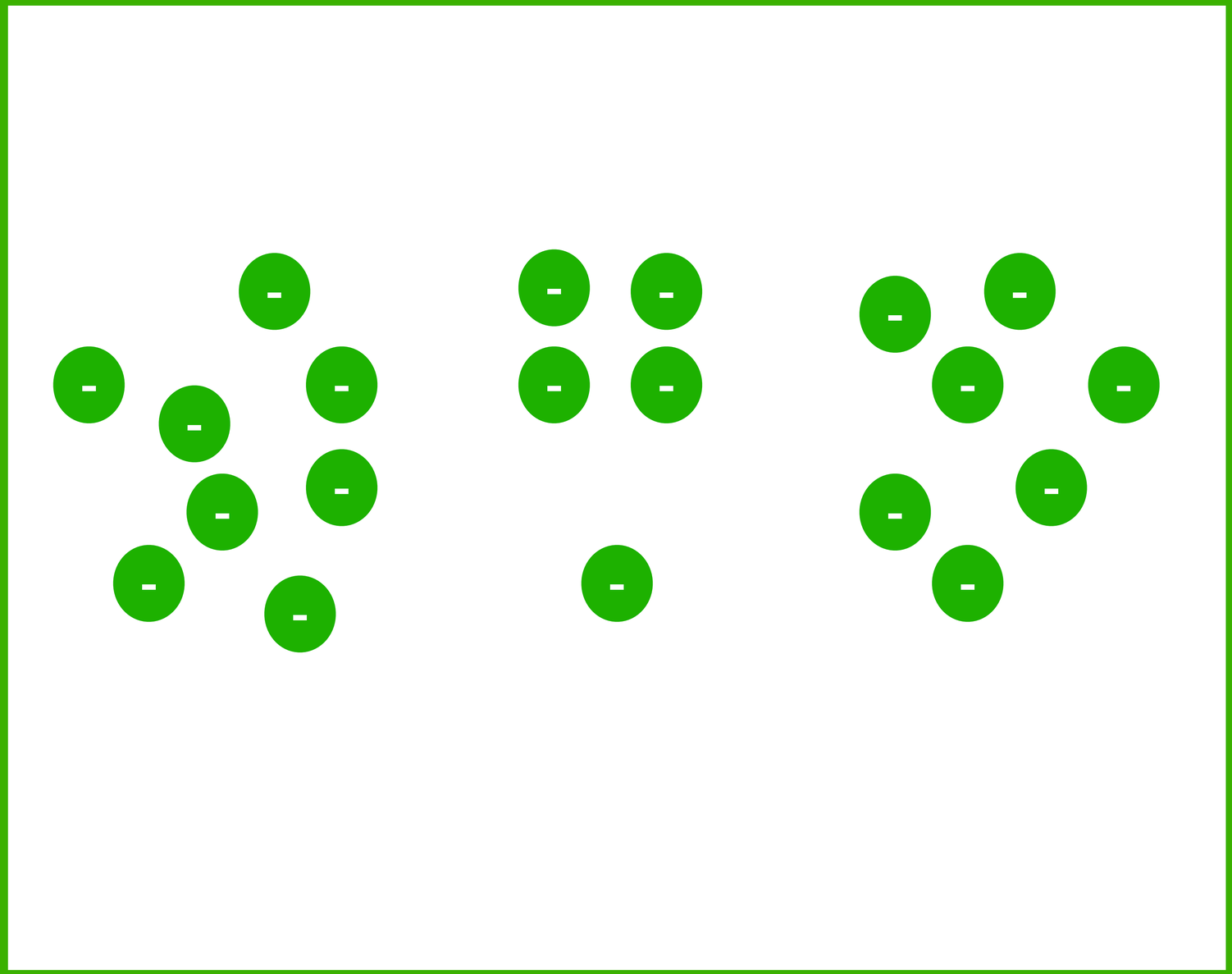




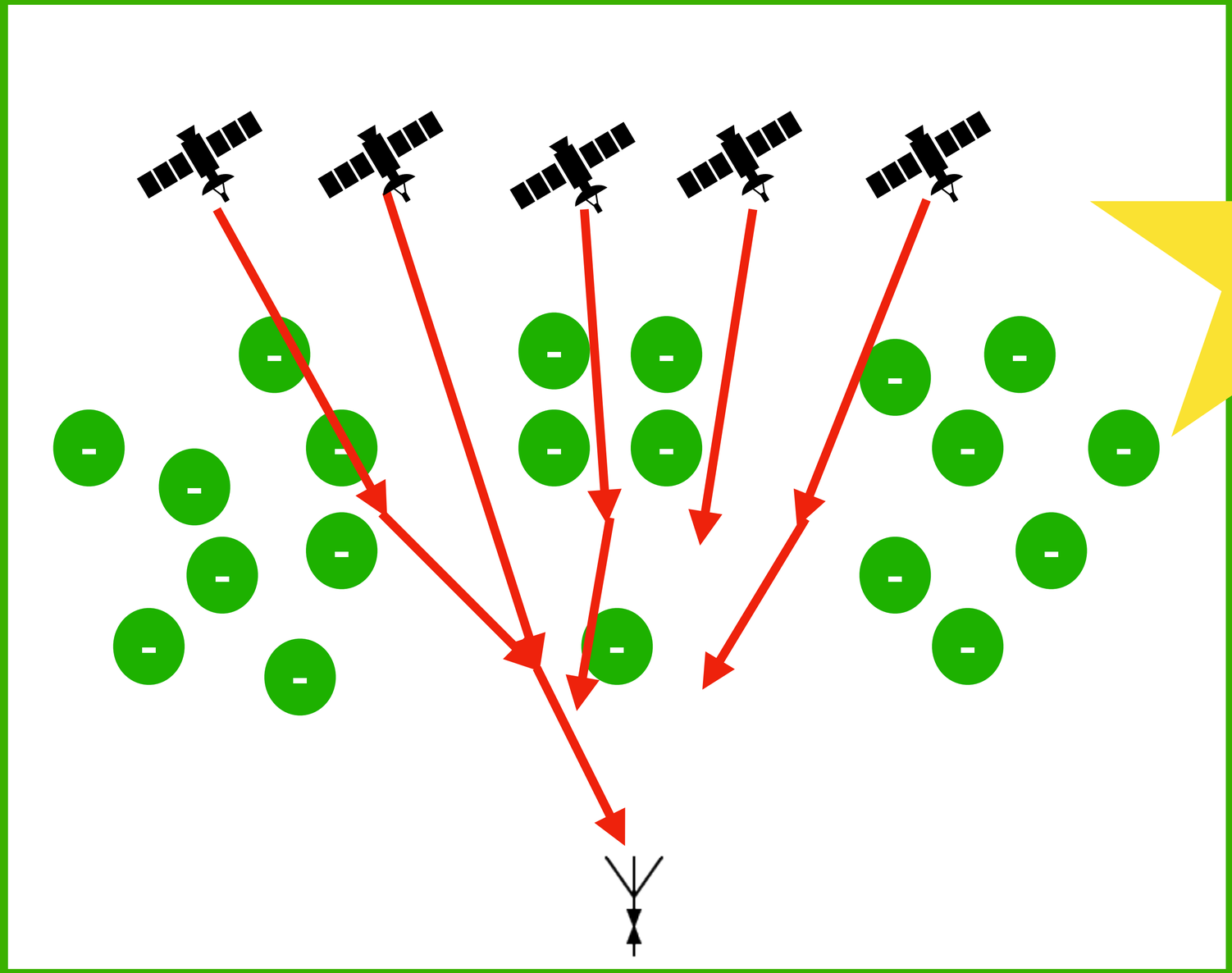




Strong gradients











Scintillation mechanisms

Post-sunset at the Equator

Auroral structures

Polar patches

Travelling ionospheric disturbances

Radiation



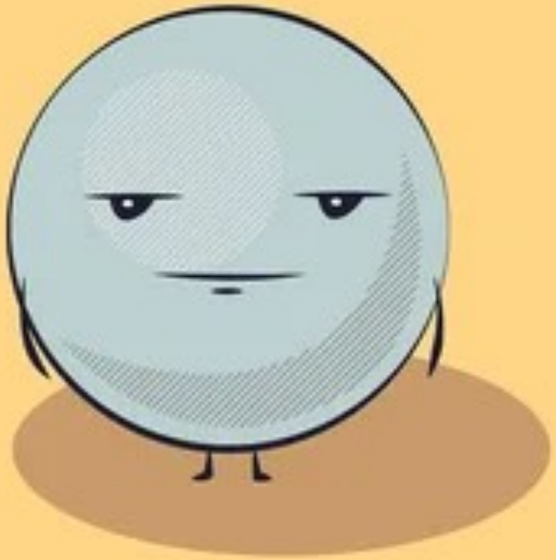
proton

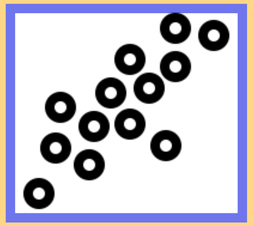


electron

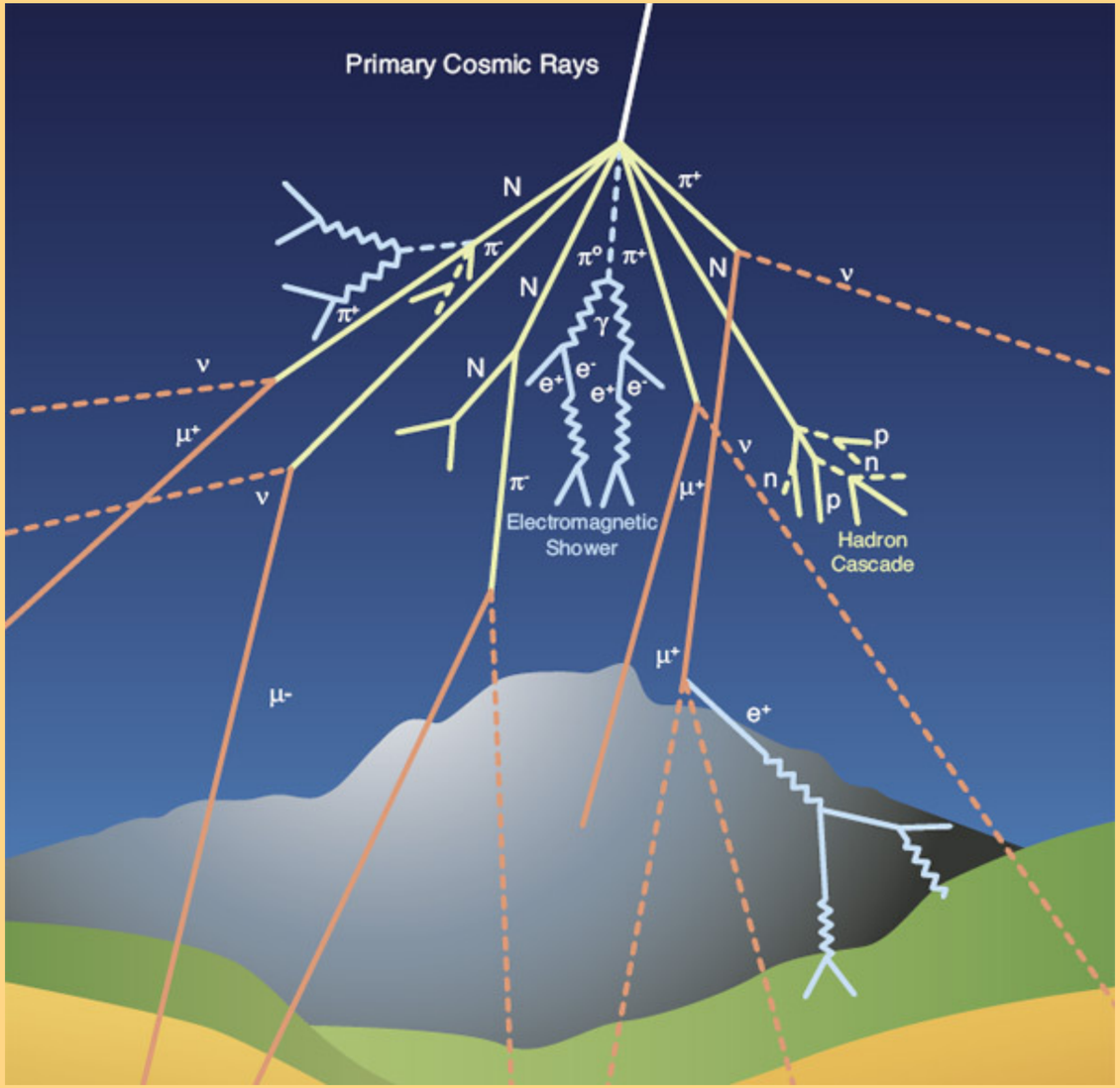


neutron





Radiation


Primary Cosmic Rays
N
π+
π-
π+
π°
π+
N
N
N
γ
e+
e-
e+
e-
ν
ν
μ+
ν
π-
Electromagnetic
Shower
μ+
ν
n
p
n
p
Hadron
Cascade
μ+
μ-
e+

Solar X-rays and gamma-rays are also ionising but do not impact civil aviation.

Why?

~~Impact: Solar Radio Burst~~



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**

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	SEVERE
Phase Scintillation	0.4	0.7	2023-04-23 20:36	0.30	QUIET		1.06	SEVERE
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.