

radiation at
flight altitude



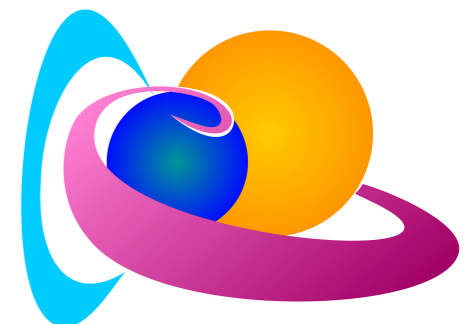
HF communication
disturbances

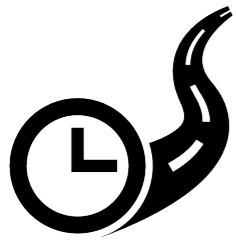


GNSS positional
errors

SWx for aviation

Petra.Vanlommel@oma.be



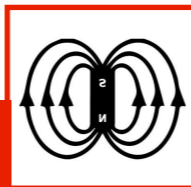
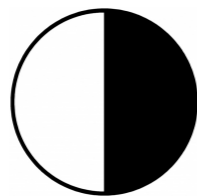


8 min

X-ray: A,B,C,M,X

Min to Hour

Illuminated area

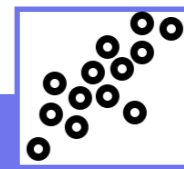


Days

Kp: 0 - 9

Day+

Polar Caps

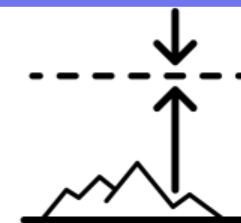


Hour

Protons:
Storm - Major Storm

Hours to Days

Polar Caps
High Altitude



PEGASUS FOR ICAO



SPACE WEATHER IMPACTING AVIATION

 radiation at
flight altitude

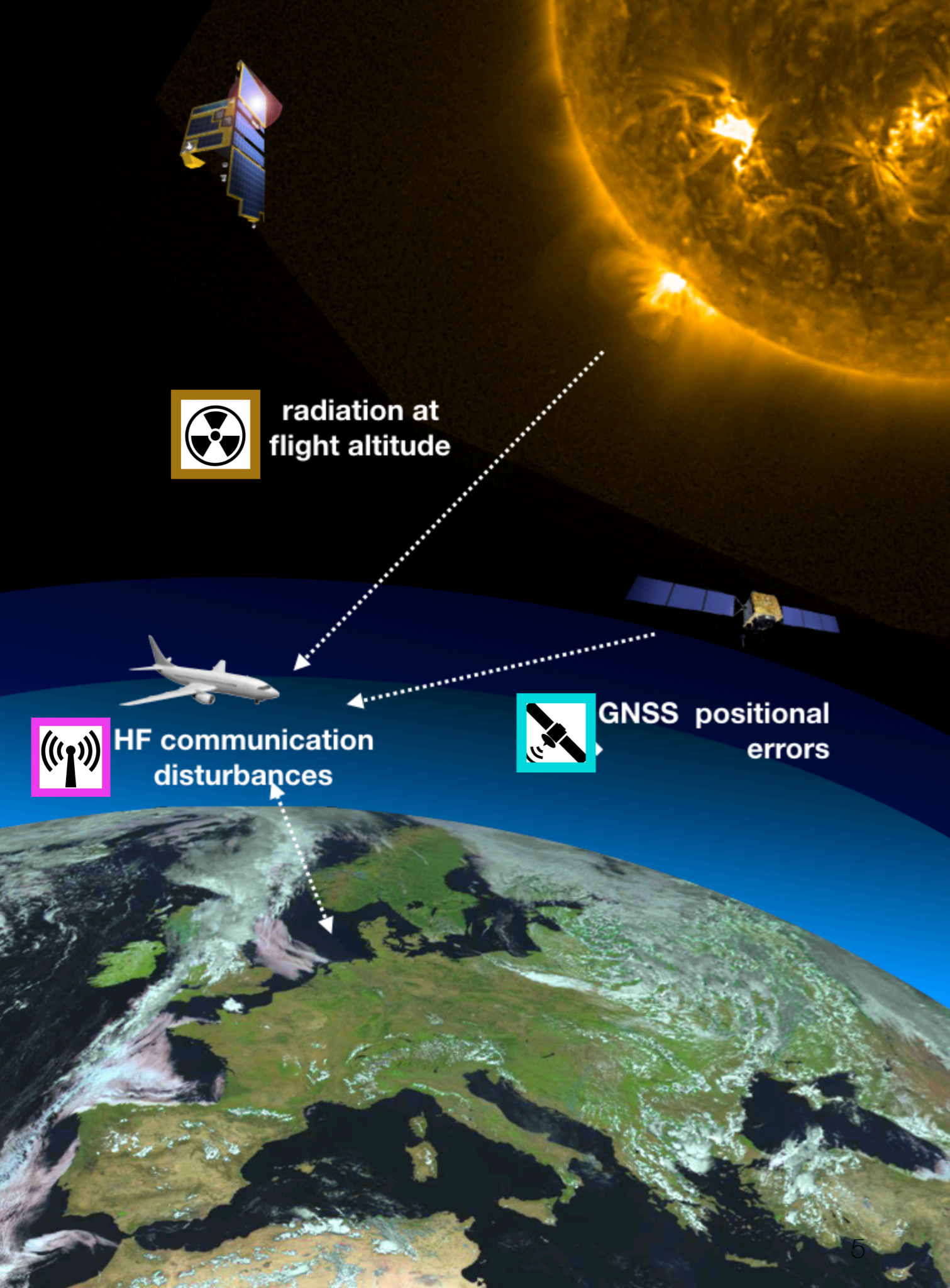


 HF communication
disturbances



 GNSS positional
errors

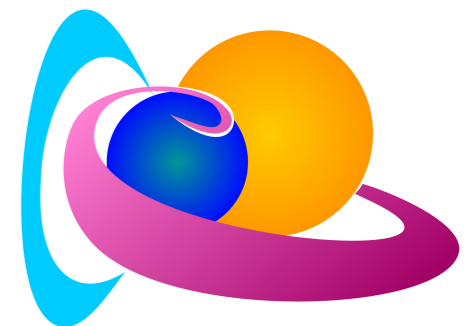







Storm parameters

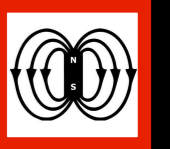
Thresholds



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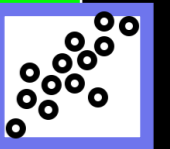






GNSS - GLOBAL NAVIGATION SATELLITE SYSTEM

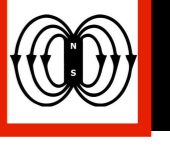
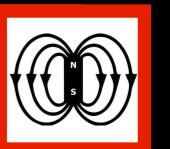
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
<u>Amplitude Scintillation</u>	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
<u>Phase Scintillation</u>	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	QUIET
<u>Vertical TEC</u>	125	175	2020-10-12 14:15	61.92	QUIET		61.93	QUIET



RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
<u>Effective Dose FL_{≤460}</u>	30	80	2020-10-12 14:20	0	QUIET		0	QUIET
<u>Effective Dose FL > 460</u>	/	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 st
<u>Auroral Absorption (AA)</u>	8	9	2020-10-12 14:16	3.0	QUIET		3.0	QUIET
<u>Polar Cap Absorption (PCA)</u>	2	5	2020-10-12 14:20	0.00	QUIET		0.00	QUIET
<u>Shortwave Fadeout (SWF)</u>	x1.0	x10.0	2020-10-12 14:17	< M.5-flare	QUIET		< M.5-flare	QUIET
<u>Post-Storm Depression (PSD)</u>	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET



SWX ADVISORY

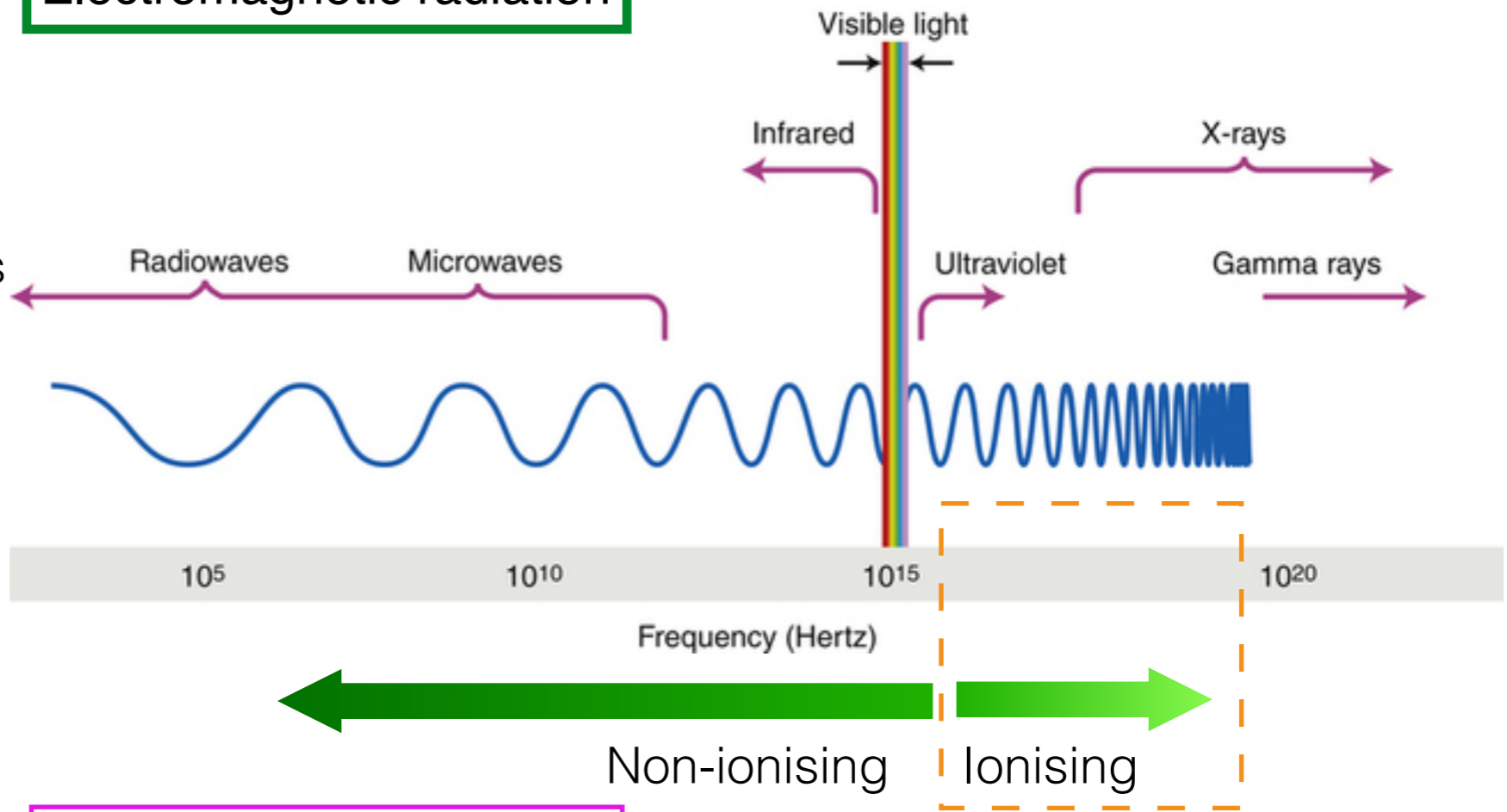
DTG: 20231010/1836Z
SWXC: PECASUS
ADVISORY NR: 2023/246
SWX EFFECT: GNSS SEV
OBS SWX: 10/1800Z EQN EQS E030 - E060
FCST SWX +6 HR: 11/0000Z EQN EQS W060 - E000
FCST SWX +12 HR: 11/0600Z NOT AVBL
FCST SWX +18 HR: 11/1200Z NO SWX EXP
FCST SWX +24 HR: 11/1800Z NOT AVBL
RMK: SPACE WEATHER EVENT (IONOSPHERIC
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=



Electromagnetic radiation

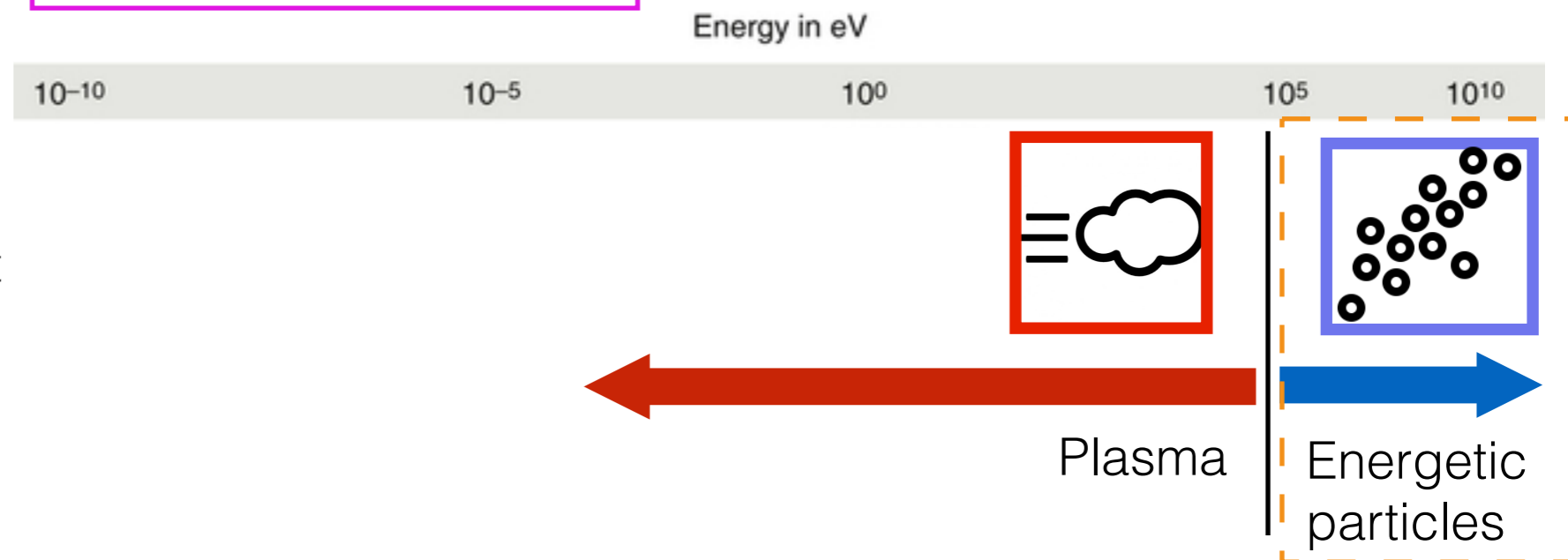


- Photons / electromagnetic waves
- Speed of light



Particles

- Atomic & sub-atomic particles
- km/s to fractions of speed of light
- Magnetic Field



IONOSPHERE



Atmospheric layer with free electrons due to

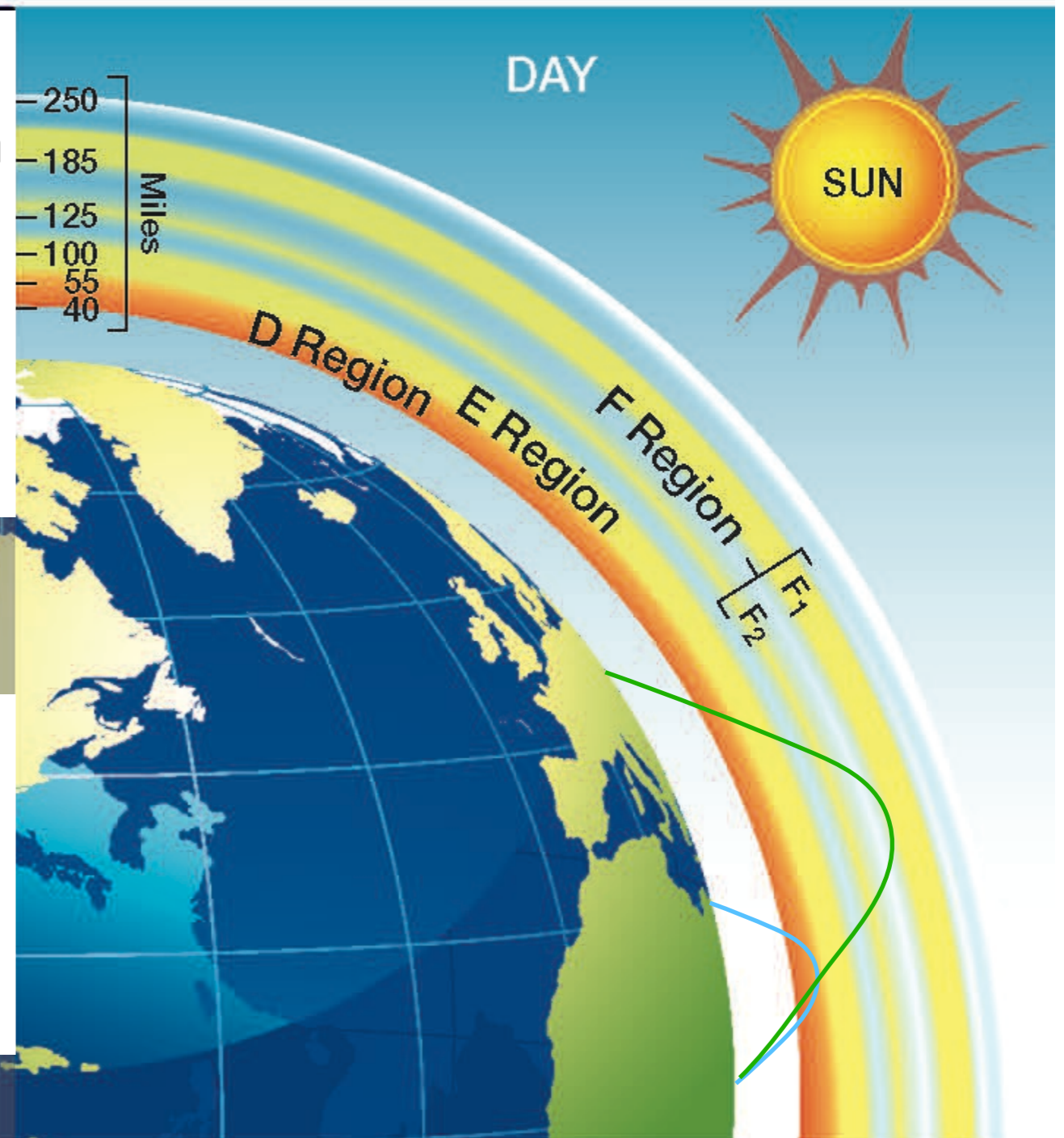
- Photo-ionisation by solar x-ray, extreme ultraviolet radiation
- Impact ionisation from energetic particles

RADIO WAVES & IONOSPHERE

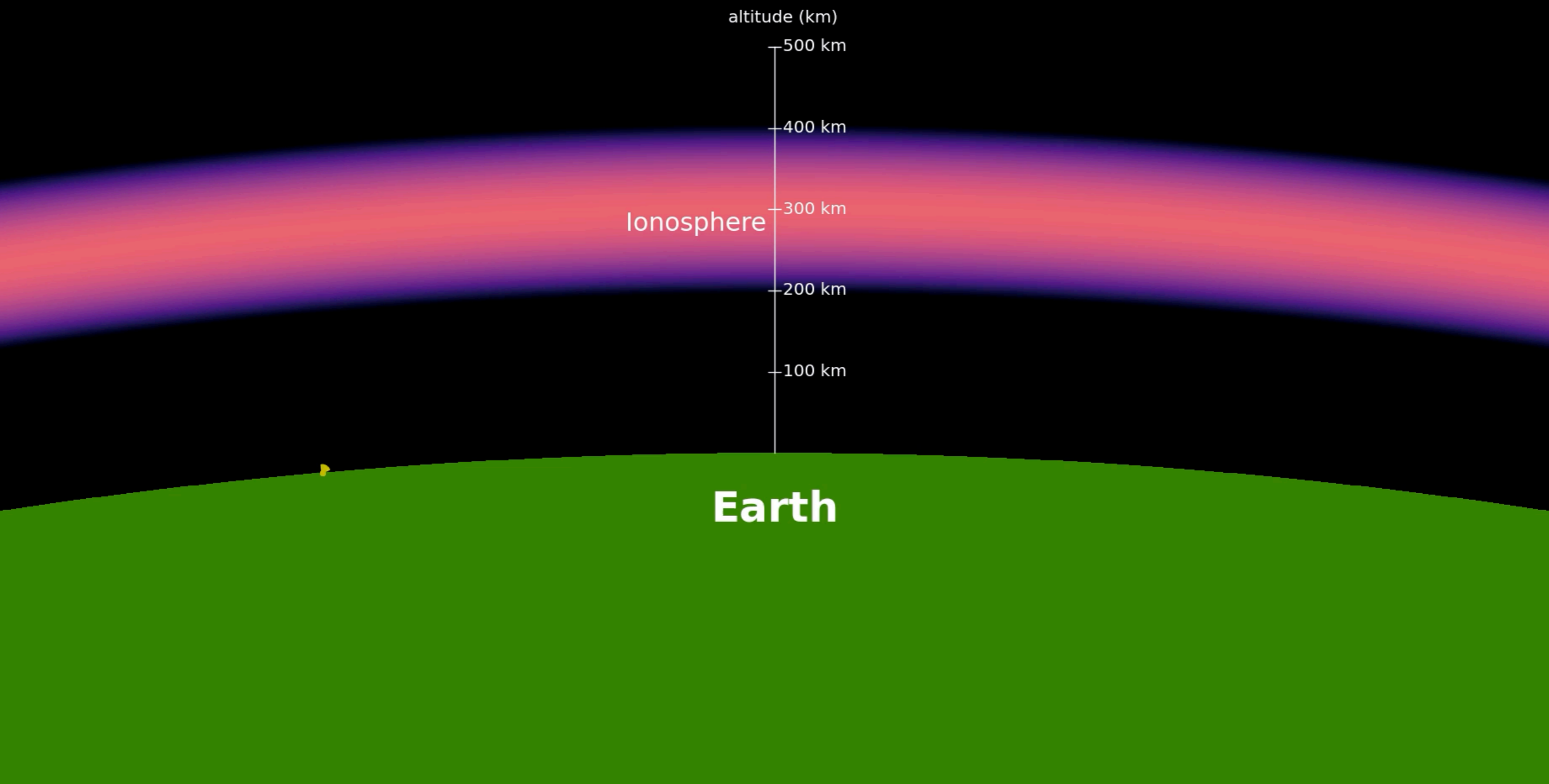
The electron content of each layer defines a critical frequency which in turn affects the refractive index of the medium

$$f_p \propto \sqrt{n_o} \quad \left| \quad n = \sqrt{1 - \frac{f_p^2}{f^2}}\right.$$

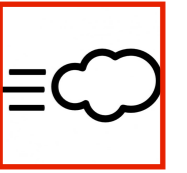
Each layer will **reflect** or **absorb** or **let pass** radio waves depending on their frequencies and on the characteristic frequency.



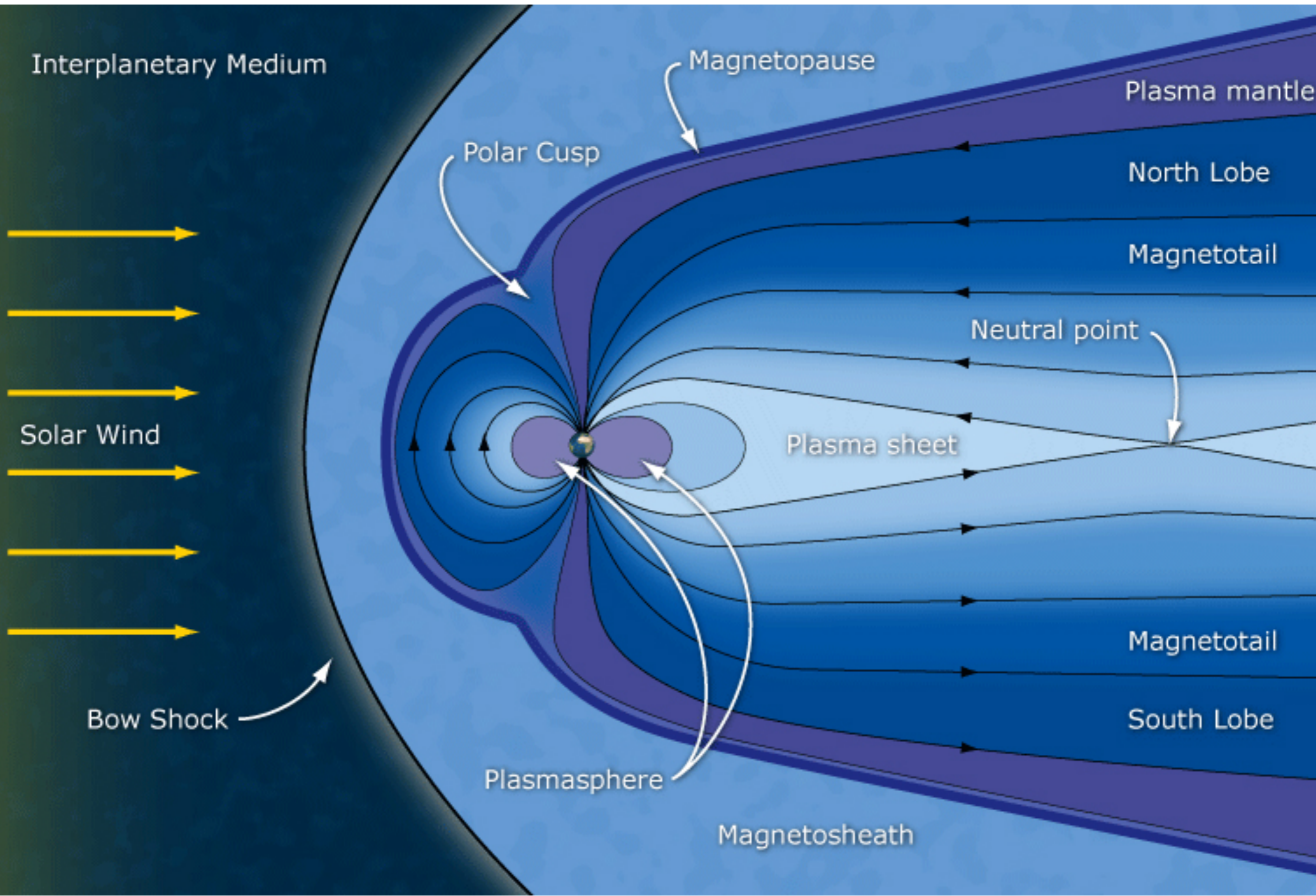
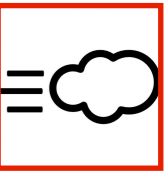
HFcom 2.8 - 35 MHz ; GNSS 1100 - 1600 MHz



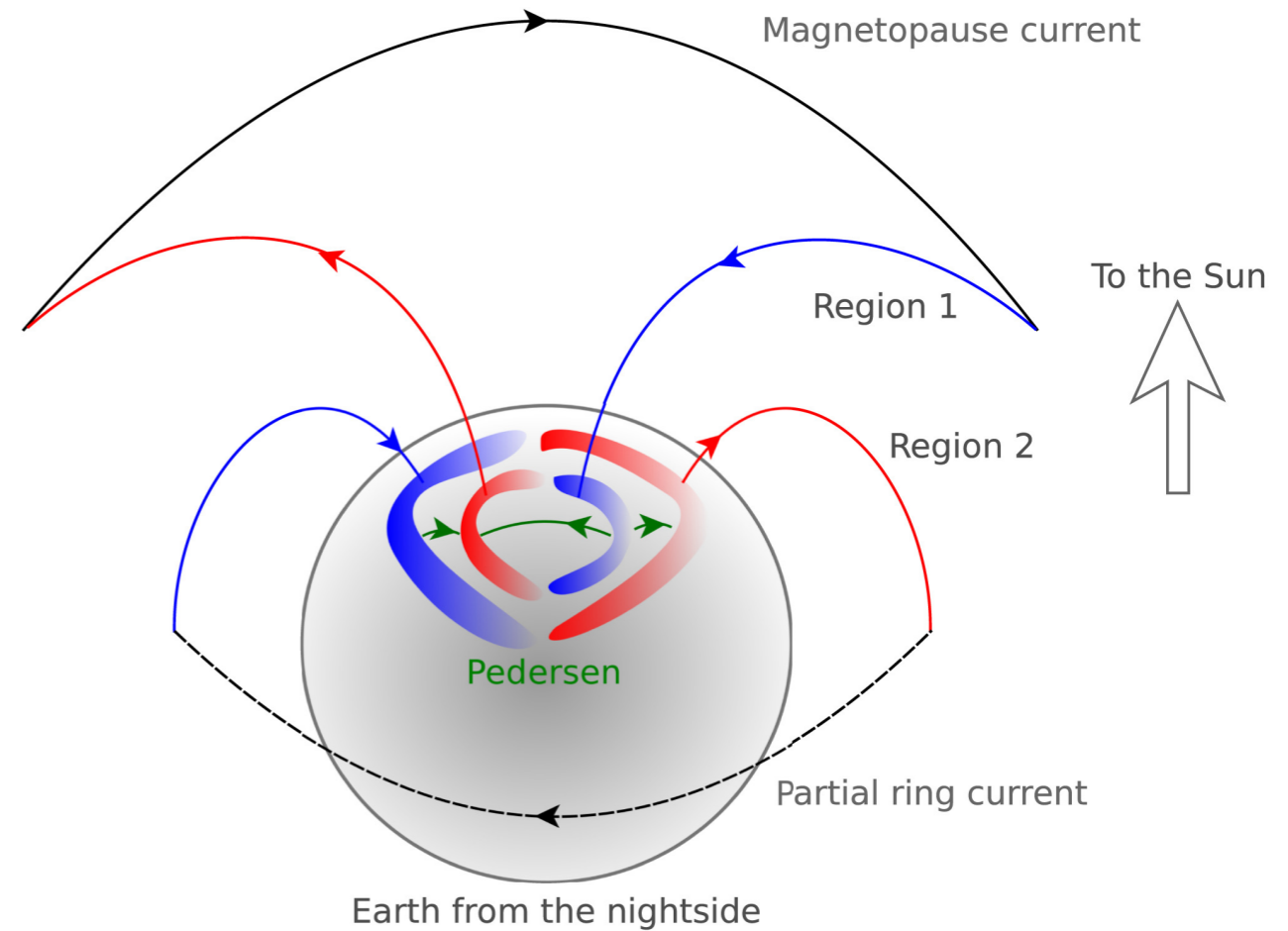
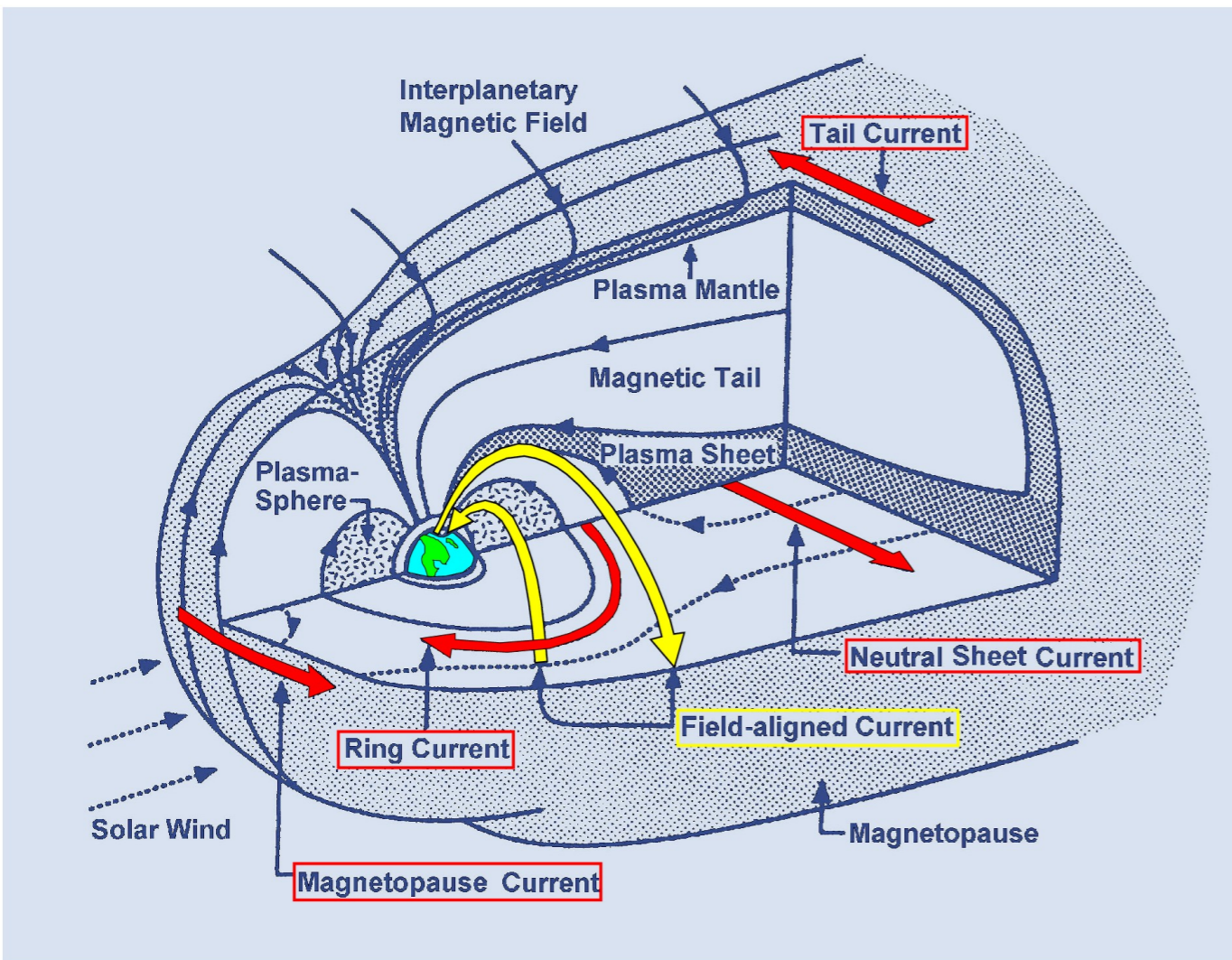
MAGNETOSPHERE-IONOSPHERE COUPLING



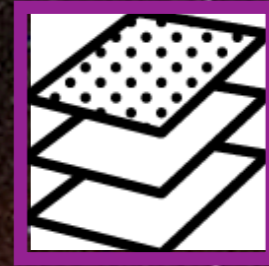
MAGNETOSPHERE-IONOSPHERE COUPLING



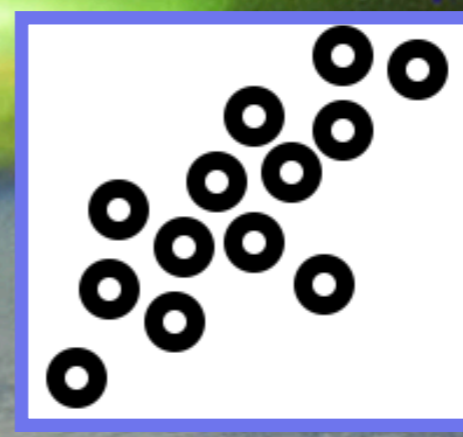
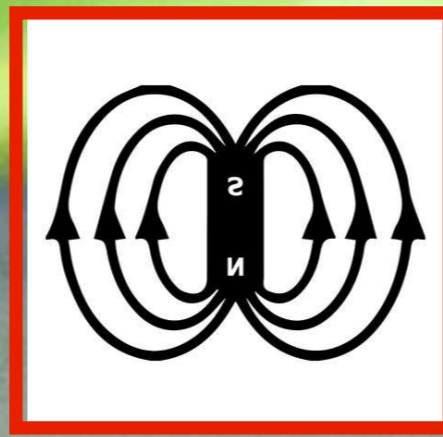
MAGNETOSPHERE-IONOSPHERE COUPLING



IONOSPHERE

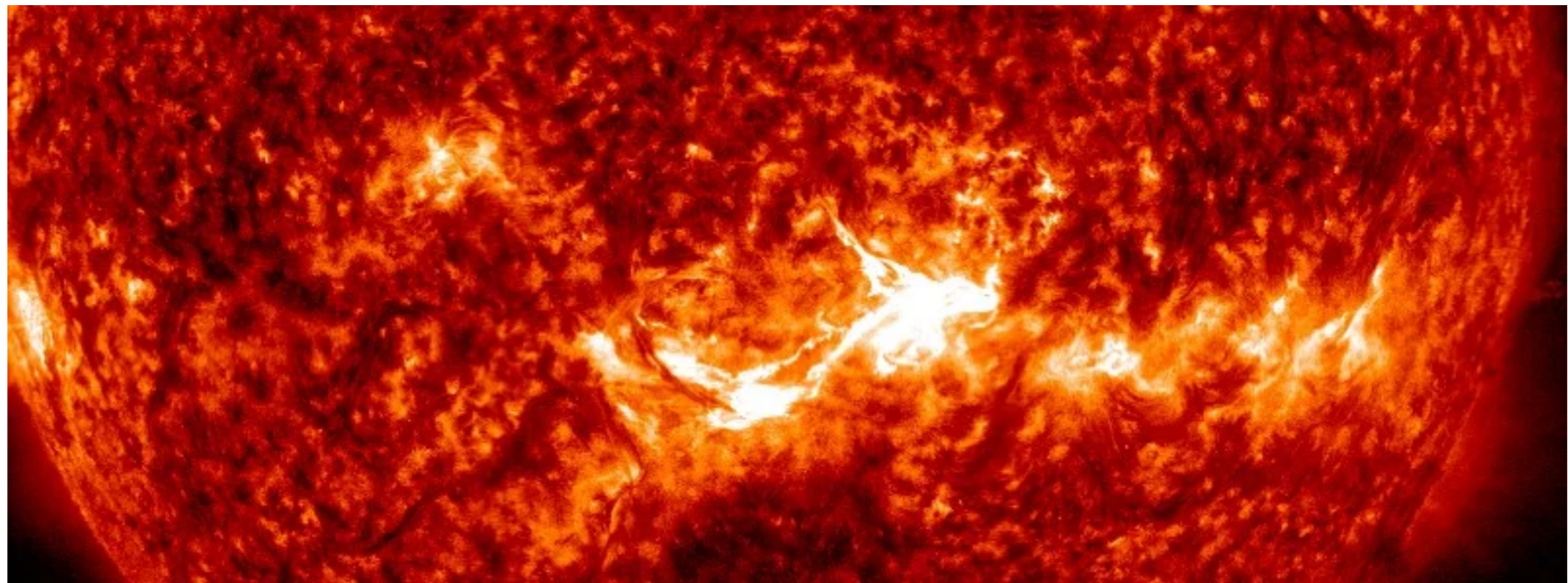


TROUBLE IN THE IONOSPHERE



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
<u>Amplitude Scintillation</u>	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
<u>Phase Scintillation</u>	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	QUIET
<u>Vertical TEC</u>	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
<u>Effective Dose FL_{≤460}</u>	30	80	2020-10-12 14:20	0	QUIET		0	QUIET
<u>Effective Dose FL > 460</u>	/	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
<u>Auroral Absorption (AA)</u>	8	9	2020-10-12 14:16	3.0	QUIET		3.0	QUIET
<u>Polar Cap Absorption (PCA)</u>	2	5	2020-10-12 14:20	0.00	QUIET		0.00	QUIET
<u>Shortwave Fadeout (SWF)</u>	x1.0	x10.0	2020-10-12 14:17	< M.5-flare	QUIET		< M.5-flare	QUIET
<u>Post-Storm Depression (PSD)</u>	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET



April 23, 17 UT

-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

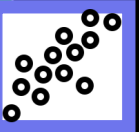
- 05/03/2024 06:53 UTC
- STATUS
- SBC
- MAIN
- GNSS
- RADIATION
- HF COM
- ARCHIVE
- Advisory
- Daily Brief
- Data
- Procedure
- Portfolio
- ICAO Docs
- RWC
- Contact
- Mute status

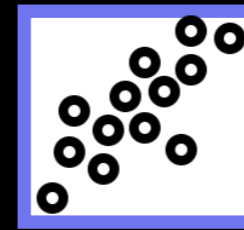
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
<u>Amplitude Scintillation</u>	0.5	0.8	2023-04-23 17:00	0.25	QUIET		0.36	QUIET
<u>Phase Scintillation</u>	0.4	0.7	2023-04-23 17:00	0.12	QUIET		0.14	QUIET
<u>Vertical TEC</u>	125	175	2023-04-23 17:00	96.98	QUIET		96.98	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
<u>Effective Dose FL ≤ 460</u>	30	80	2023-04-23 17:00	0	QUIET		0	QUIET
<u>Effective Dose FL > 460</u>	/	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
<u>Auroral Absorption (AA)</u>	8	9	2023-04-23 17:00	5.3	QUIET		5.3	QUIET
<u>Polar Cap Absorption (PCA)</u>	2	5	2023-04-23 17:00	2.75	MODERATE		2.94	MODERATE
<u>Shortwave Fadeout (SWF)</u>	x1.0	x10.0	2023-04-23 17:00	< M5 flare	QUIET		< M5 flare	QUIET
<u>Post-Storm Depression (PSD)</u>	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.





April 23, 17 UT

-24h -12h -6h -3h -1h -5m Submit 2023-04-23 16:55 now +5m +1h +3h +6h +12h +24h

HF/PCA DASHBOARDS on 2023-04-23 16:55 UTC



10/10/2023
20:01 UTC

STATUS
ODC

MAIN

GNSS

RADIATION

HF COM

ARCHIVE

Advisory

Daily Brief

Data

Procedures

Portfolio

ICAO Docs

RWC

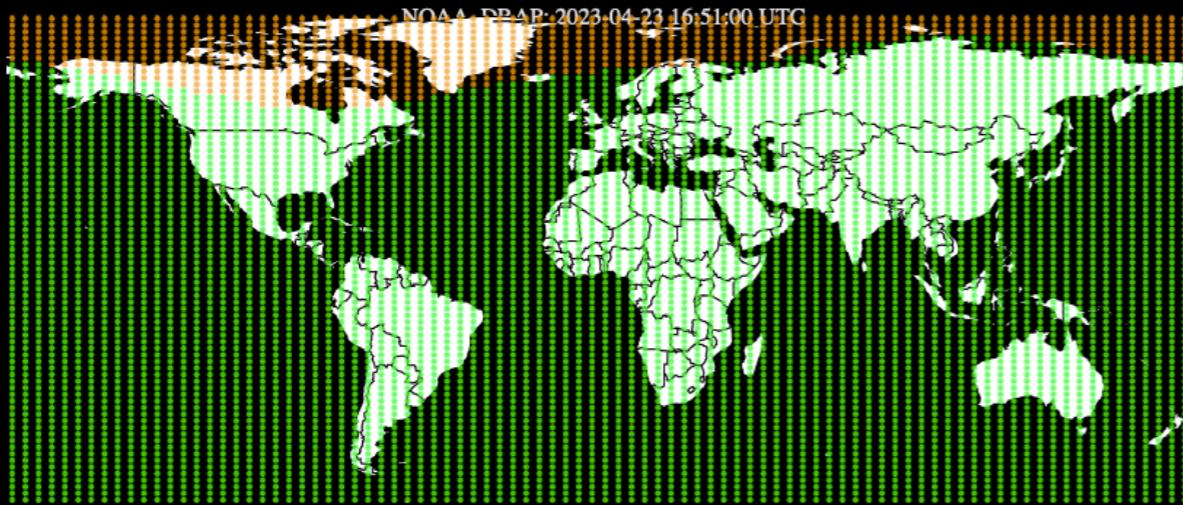
Contact

Mute status

OnCall Report

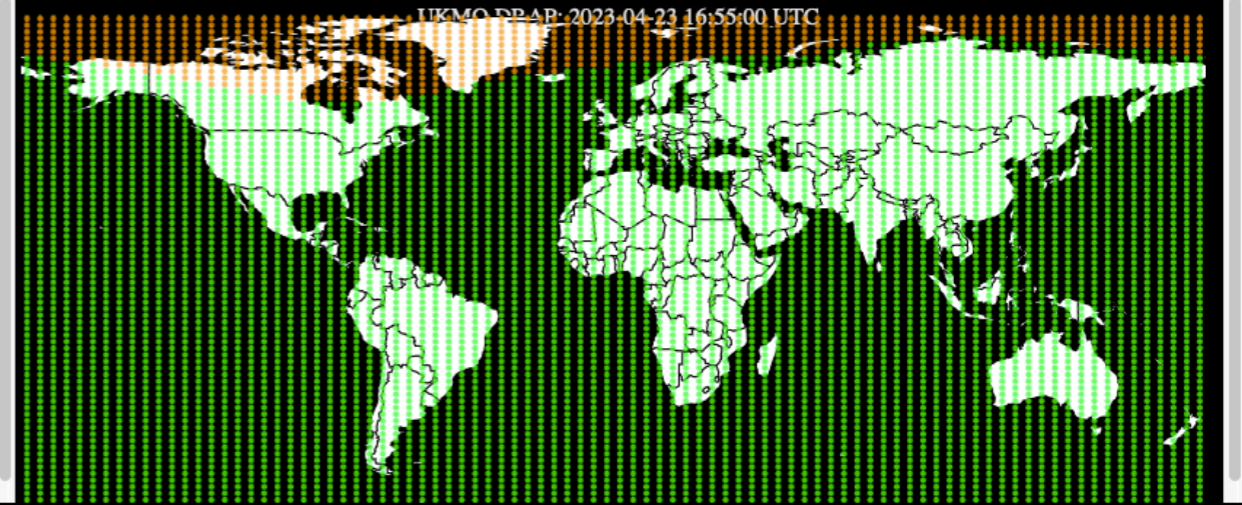
HF/PCA (dB from 30MHz data) - NOAA

NOAA DBAP: 2023-04-23 16:51:00 UTC

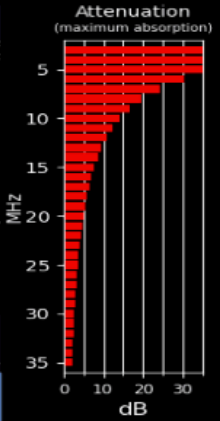
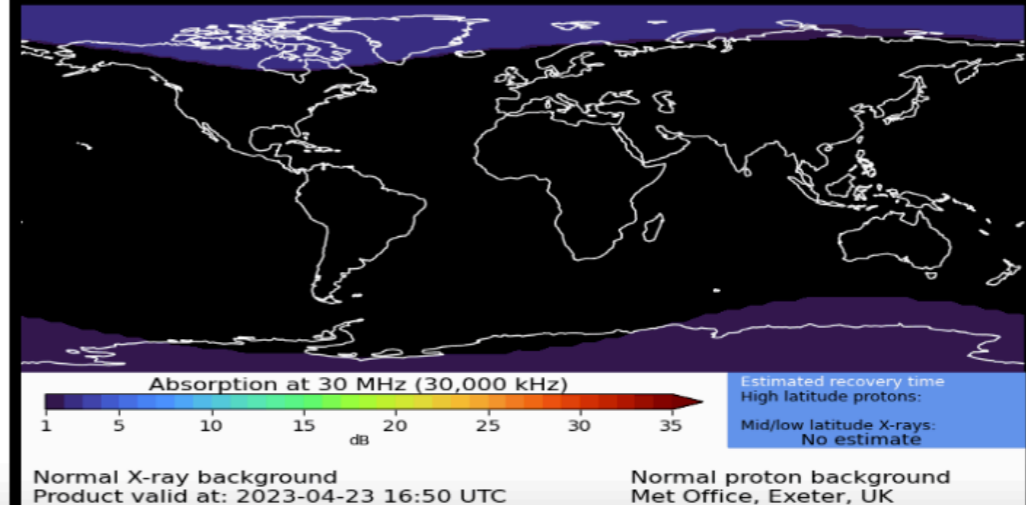
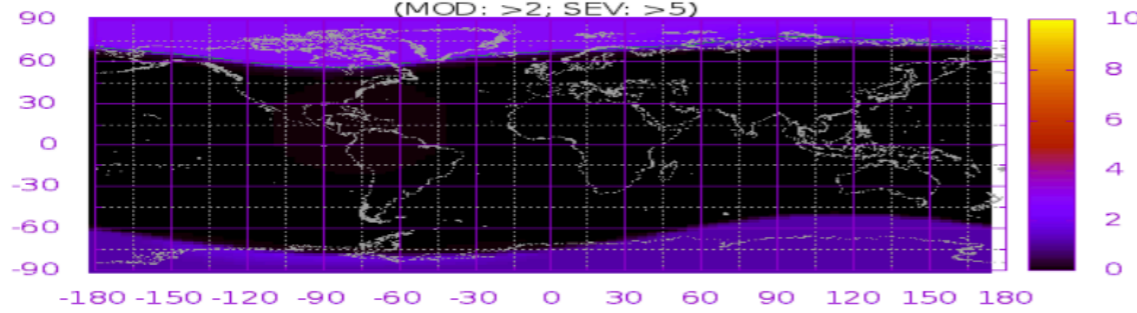


HF/PCA (dB from 30MHz data) - UKMO

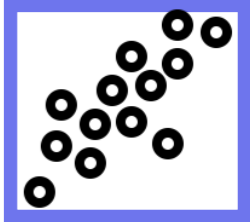
UKMO DBAP: 2023-04-23 16:55:00 UTC



Absorption [dB] at 30 MHz on 2023-04-23 16:51 UTC
(MOD: >2; SEV: >5)

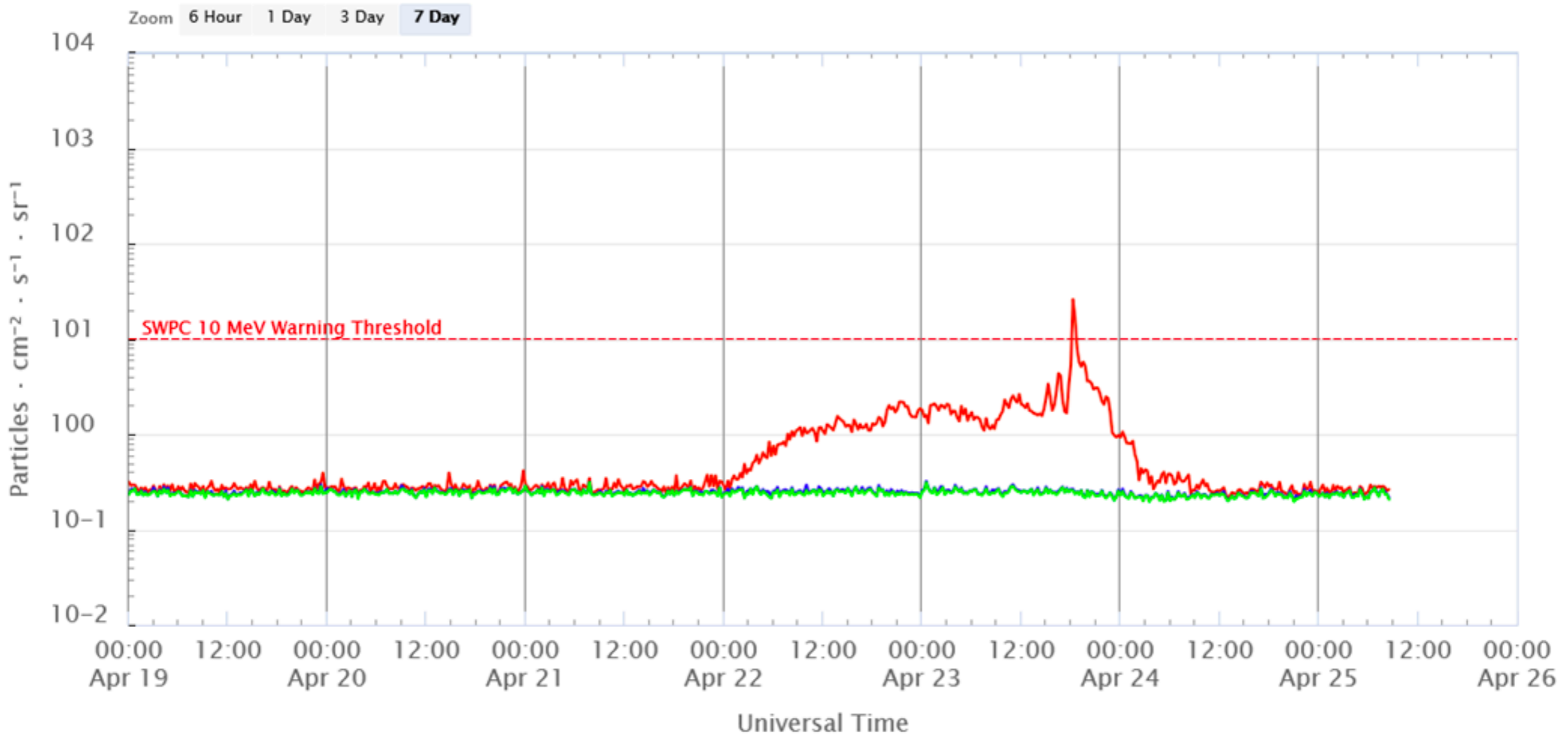


Proton Event



GOES Proton Flux (5-minute data)

April 23, 17 UT

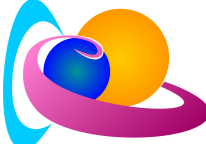


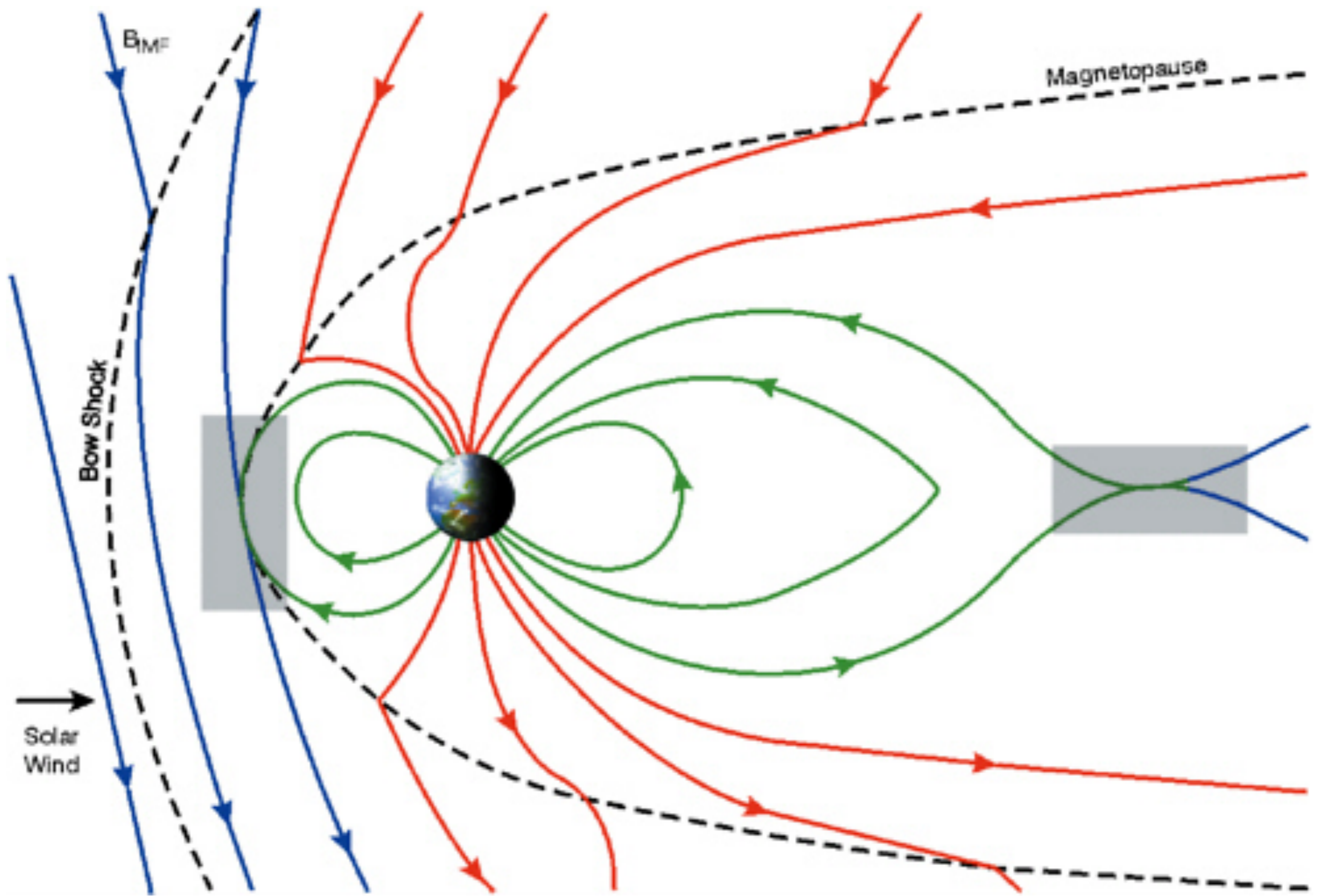
— GOES-16 ≥ 10 MeV — GOES-16 ≥ 50 MeV — GOES-16 ≥ 100 MeV

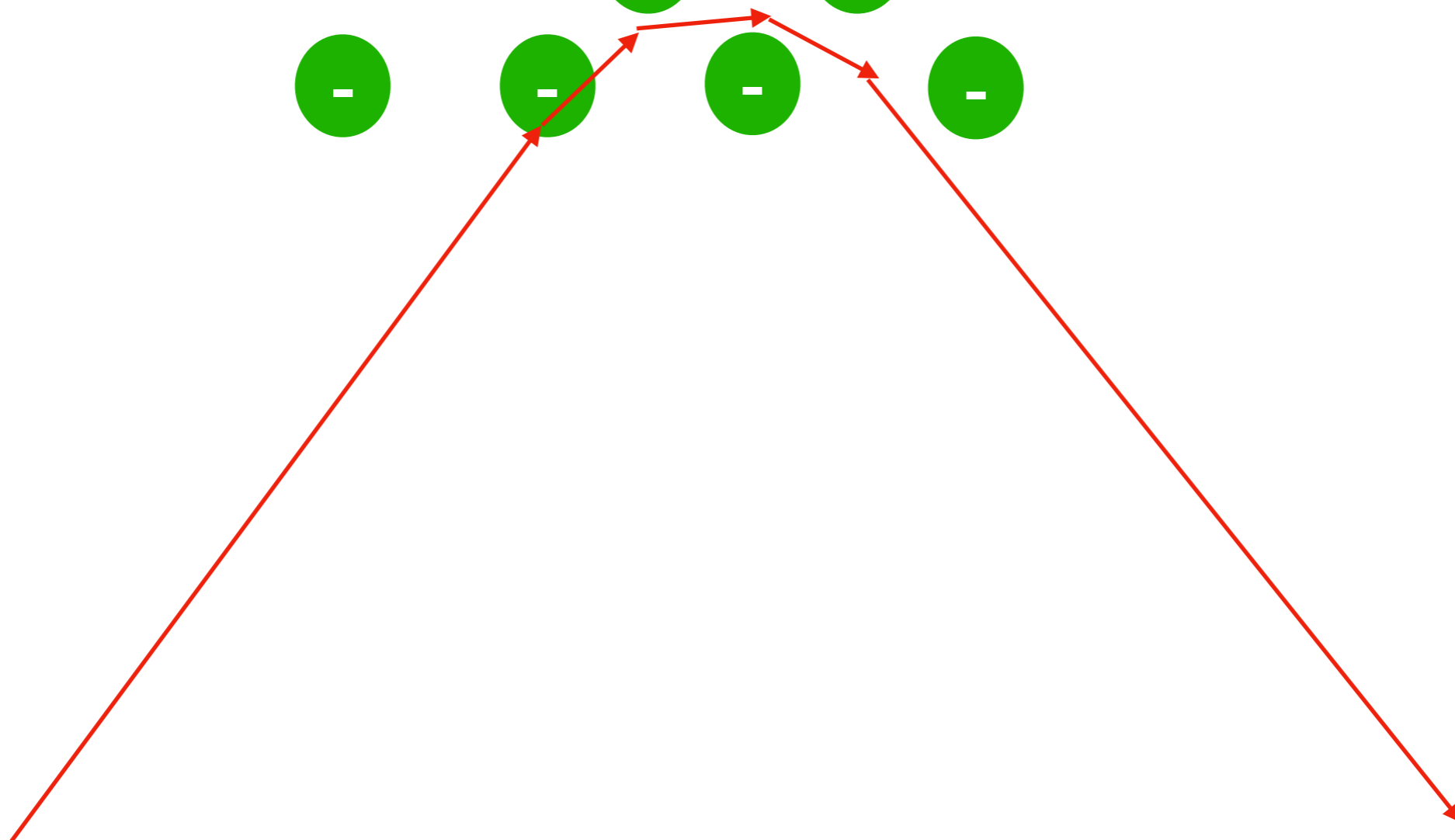
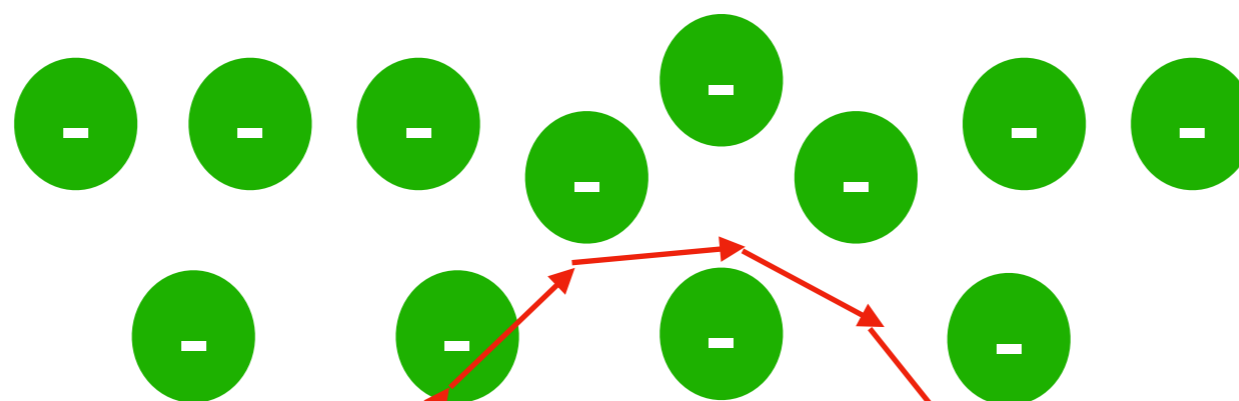
Updated 2023-04-25 08:40 UTC

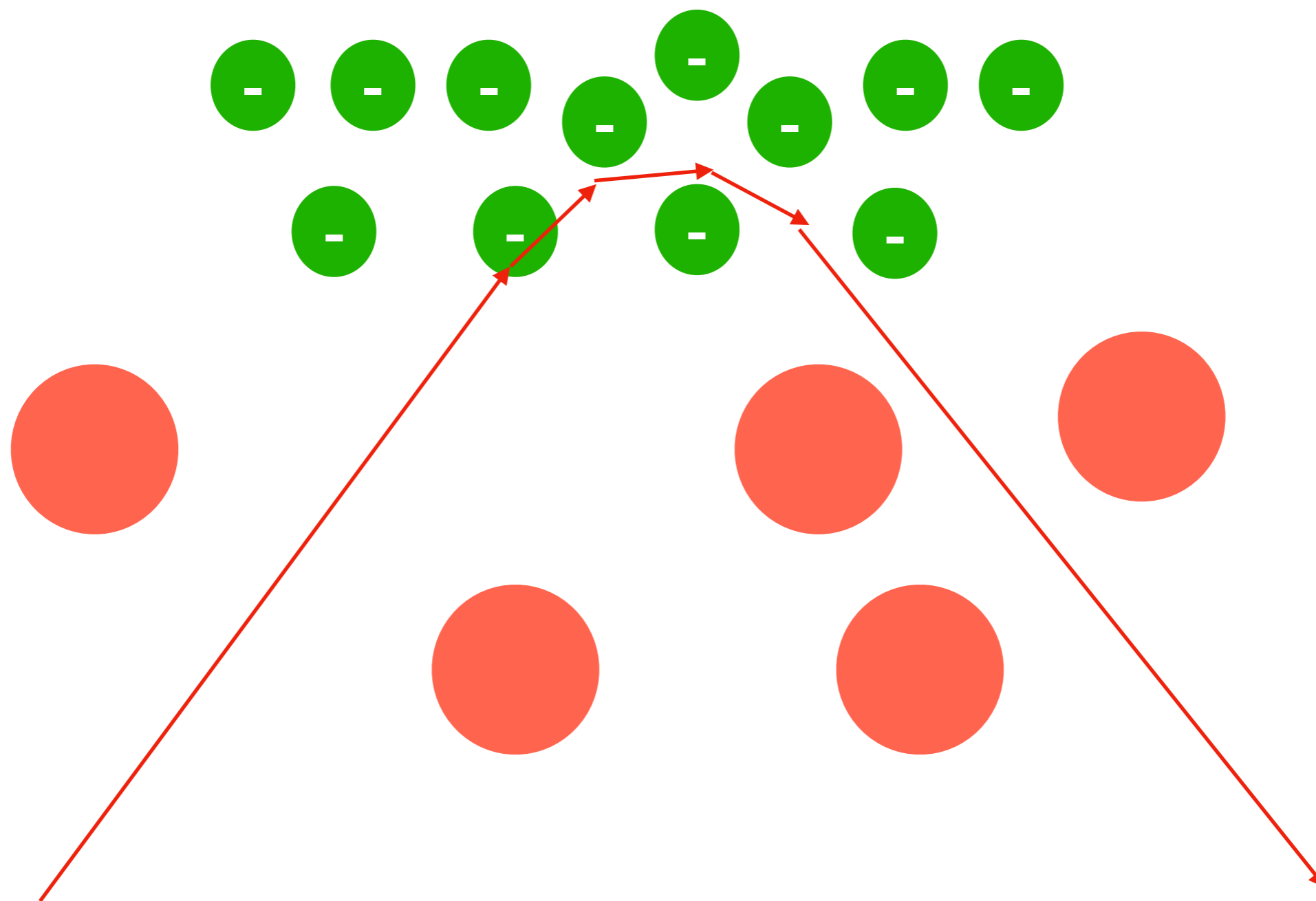
Space Weather Prediction Center

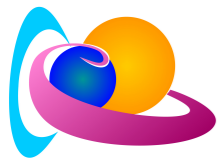
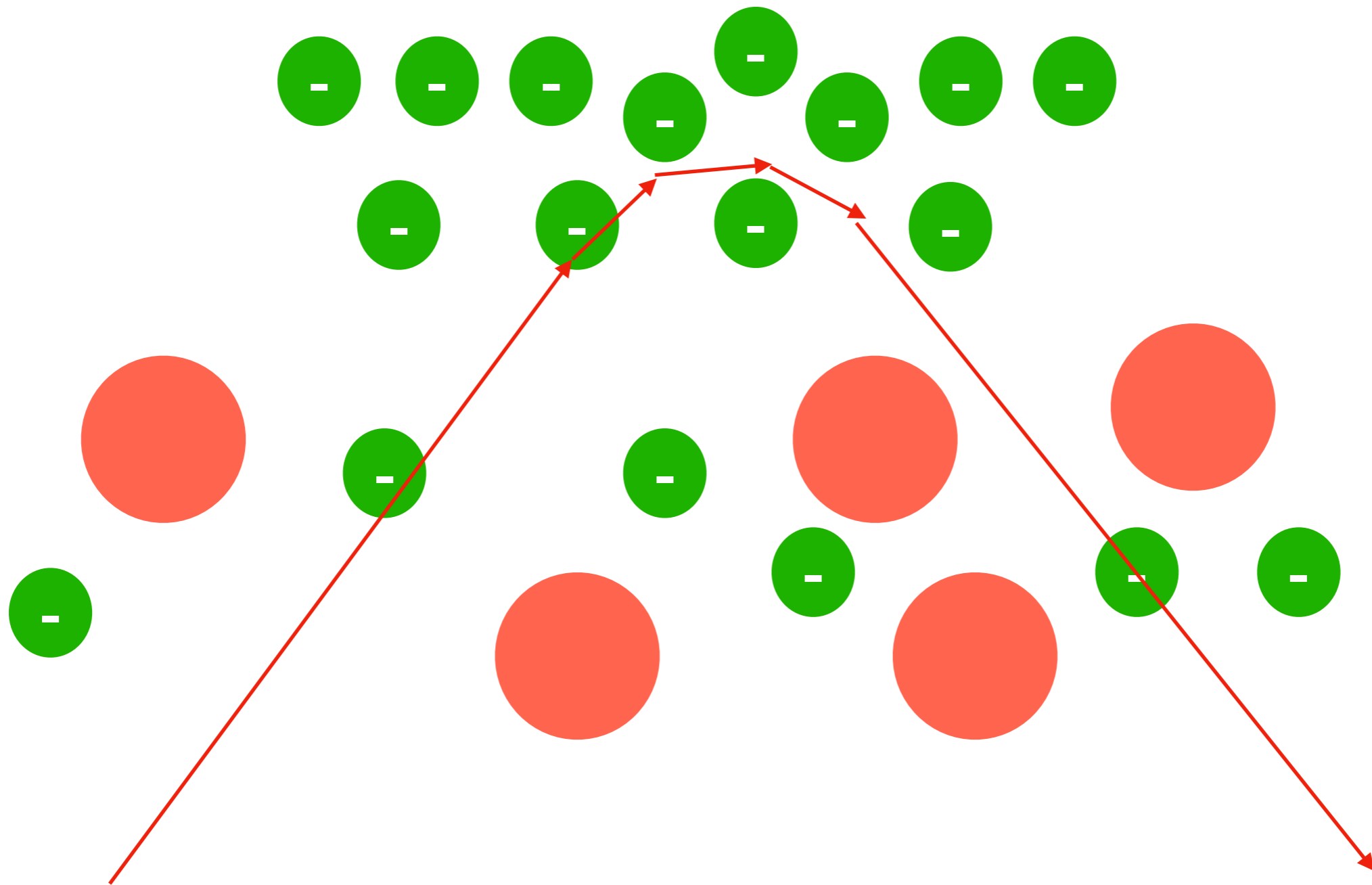
Quiet
 Proton event expected (10 pfu at >10 MeV)
 Major proton event expected (100 pfu at >100 MeV)
 Proton event in progress (>10 MeV)
 Warning condition (activity levels expected to increase, but no numeric forecast given)



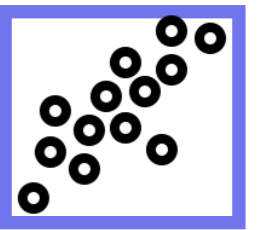
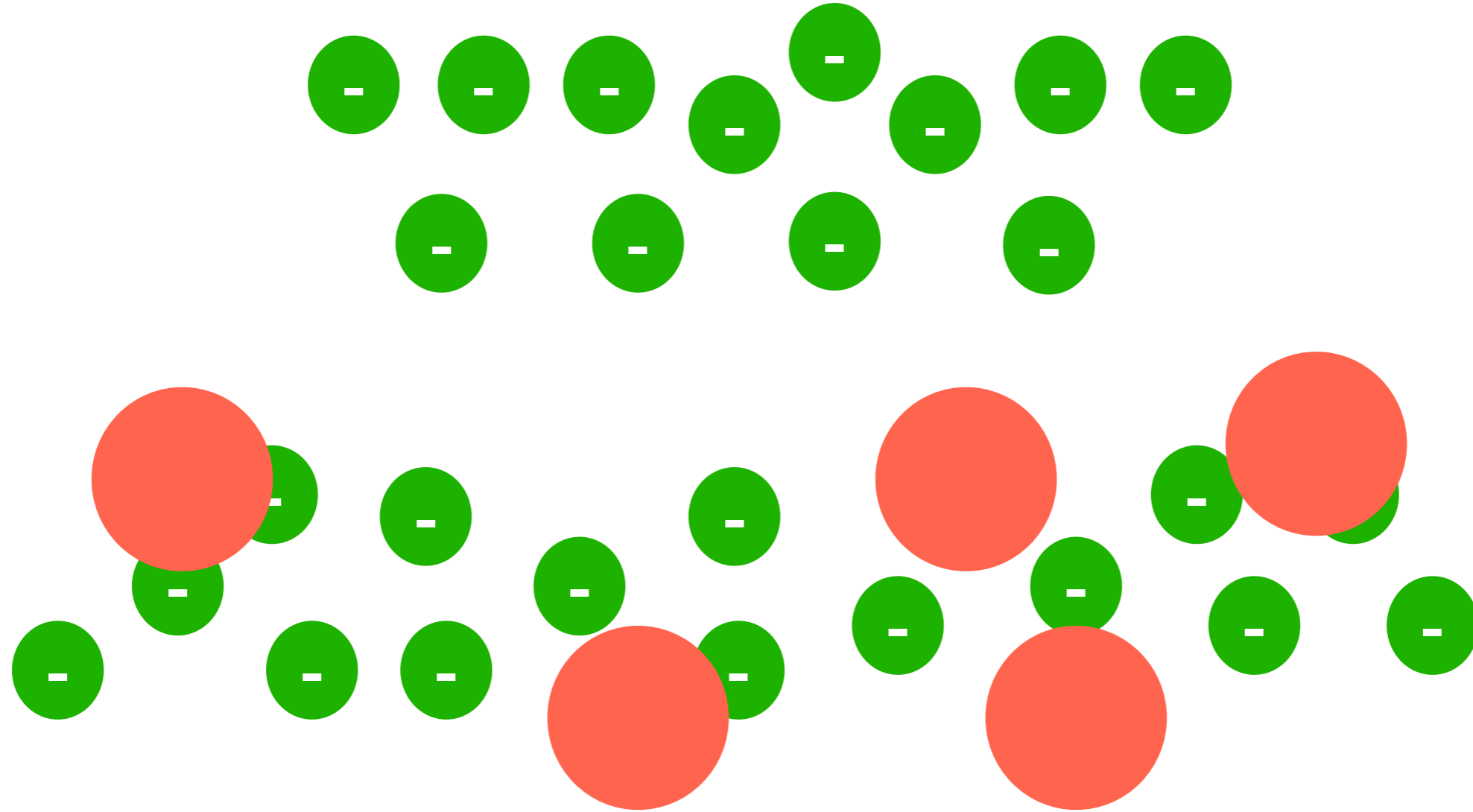




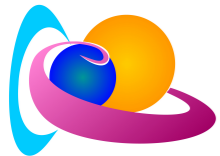
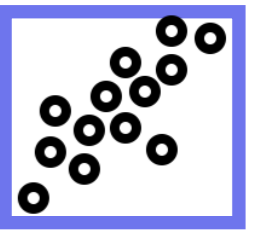
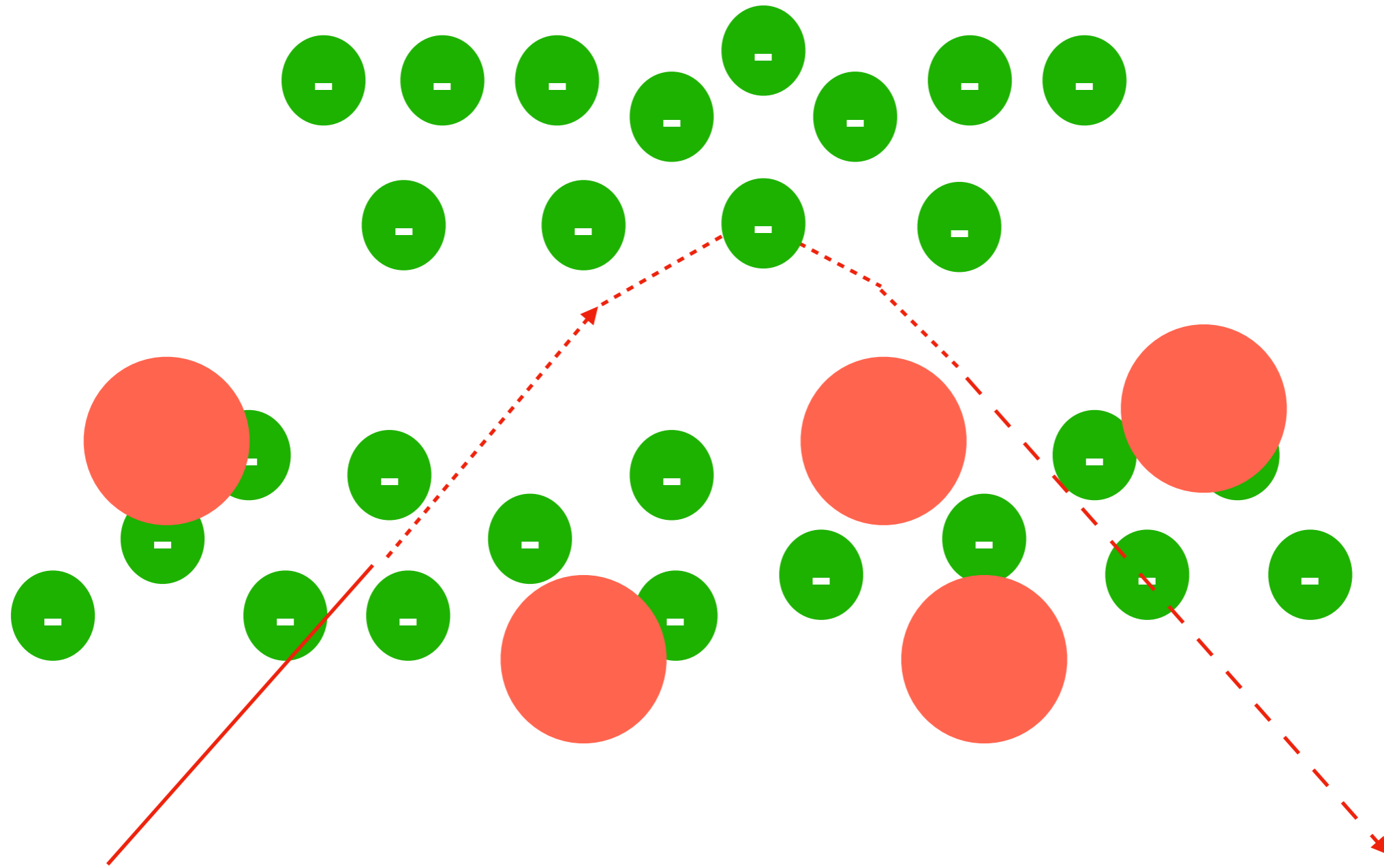




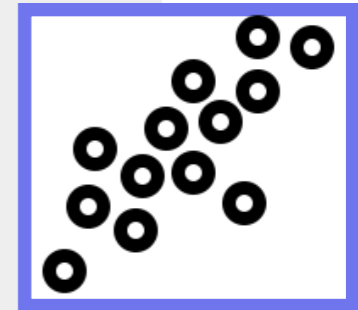
PCA



PCA



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=



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
<u>Amplitude Scintillation</u>	0.5	0.8	2023-04-23 18:50	0.40	QUIET		0.40	QUIET
<u>Phase Scintillation</u>	0.4	0.7	2023-04-23 18:50	0.26	QUIET		0.26	QUIET
<u>Vertical TEC</u>	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
<u>Effective Dose FL ≤ 460</u>	30	80	2023-04-23 18:50	0	QUIET		0	QUIET
<u>Effective Dose FL > 460</u>	/	80	2023-04-23 18:50	0	QUIET		0	QUIET

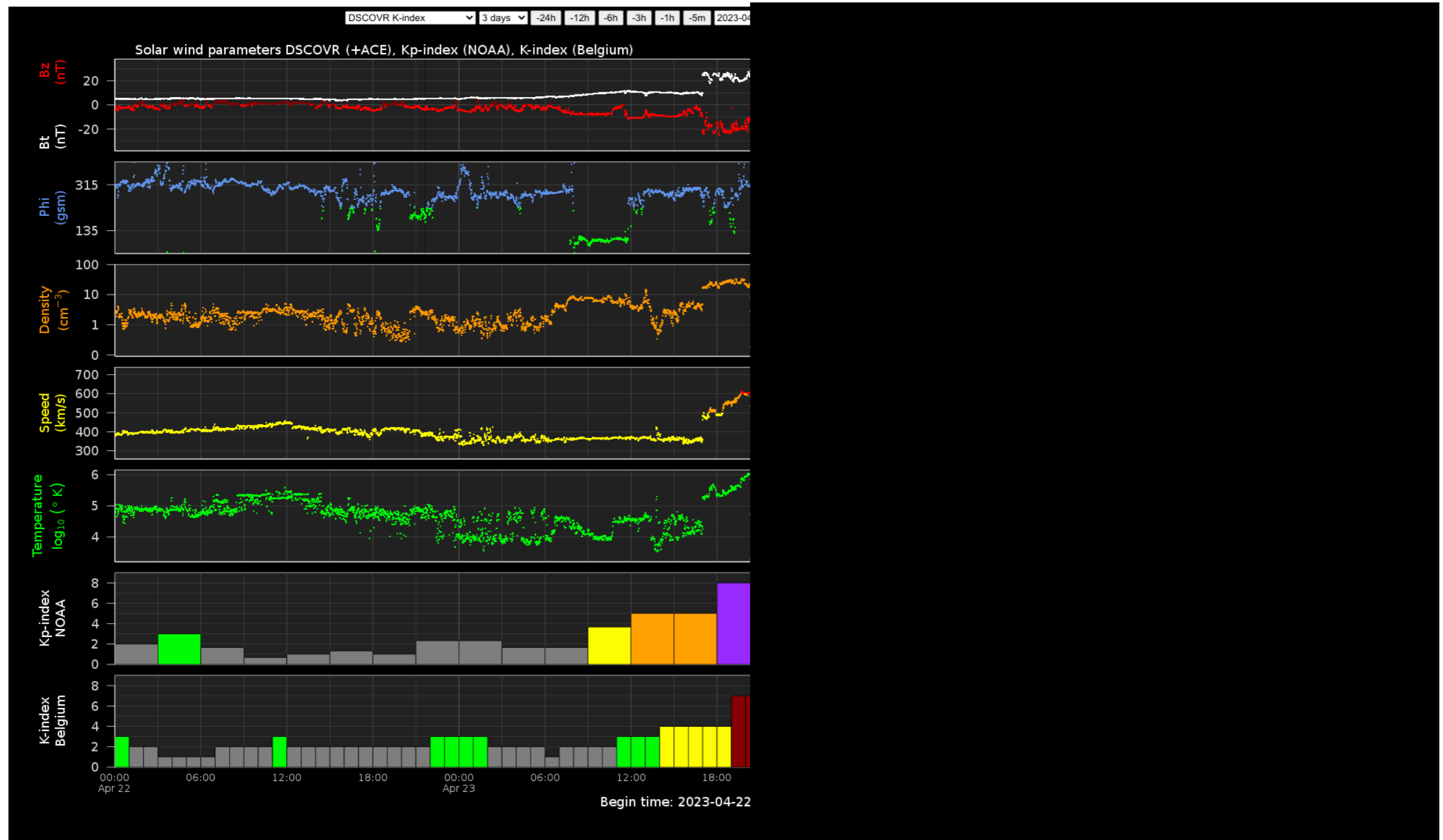
HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
<u>Auroral Absorption (AA)</u>	8	9	2023-04-23 18:50	8.0	MODERATE		8.0	MODERATE
<u>Polar Cap Absorption (PCA)</u>	2	5	2023-04-23 18:50	3.13	MODERATE		4.64	MODERATE
<u>Shortwave Fadeout (SWF)</u>	x1.0	x10.0	2023-04-23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

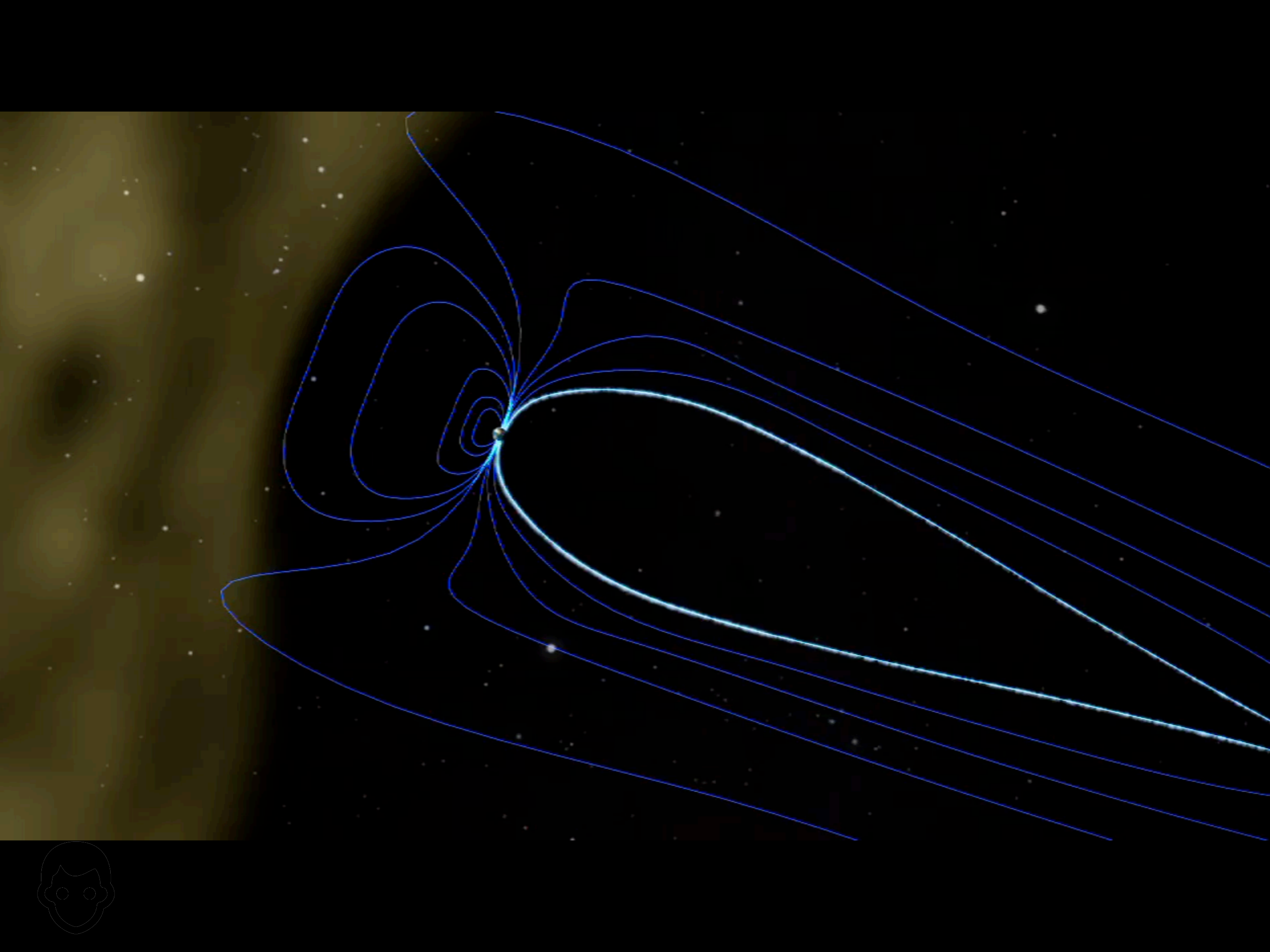


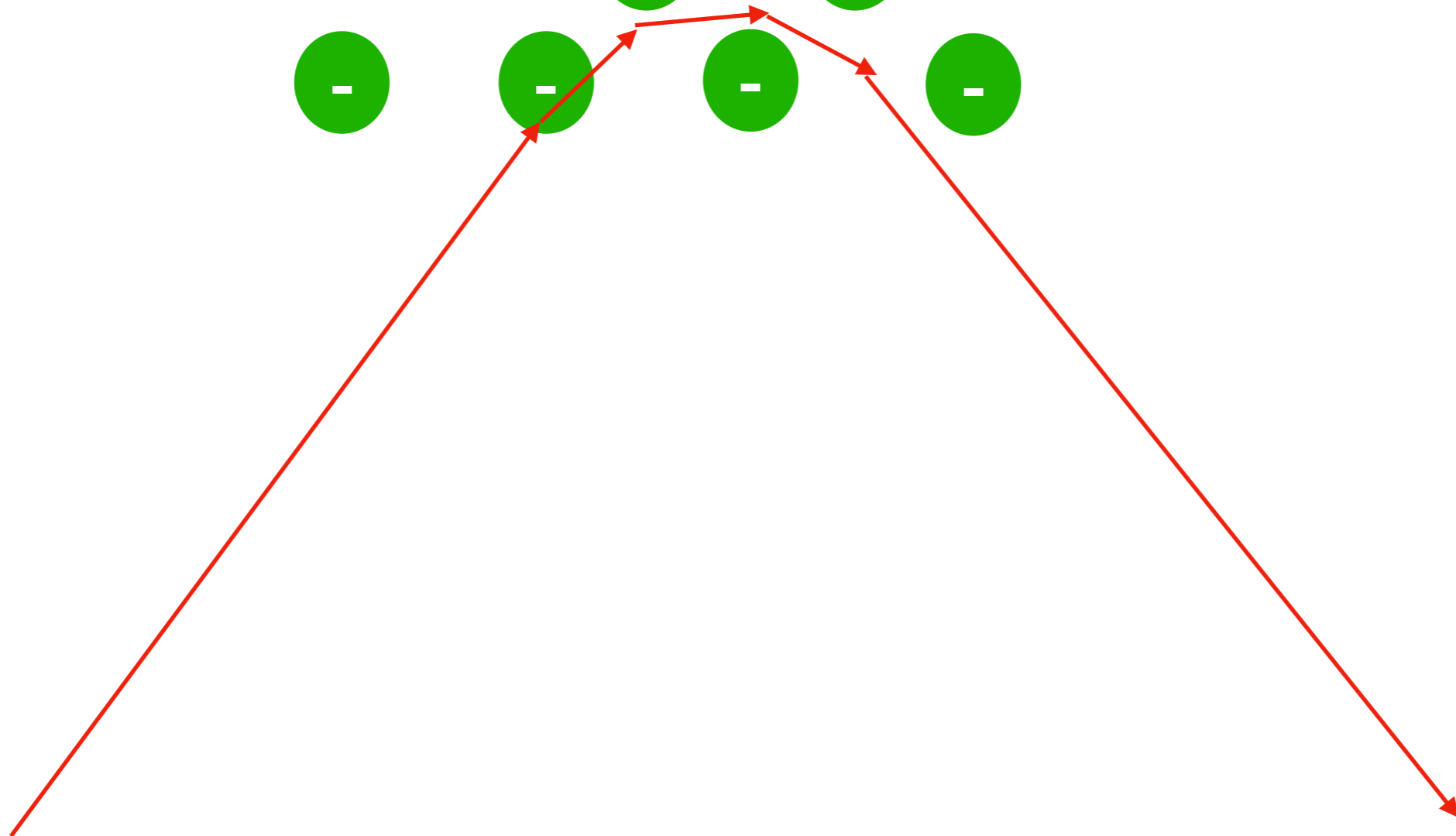
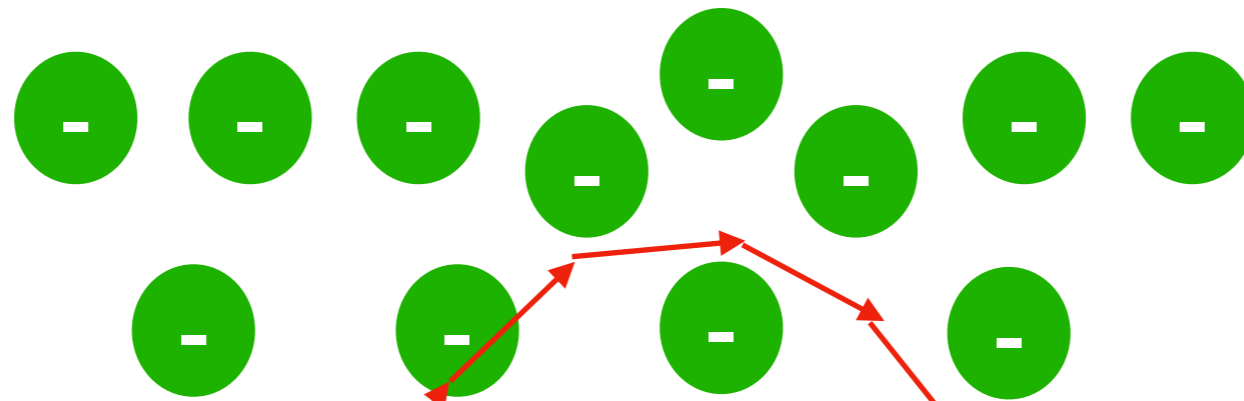
Sound alarm is triggered when MOD or SEV thresholds are exceeded or in case of data outages.

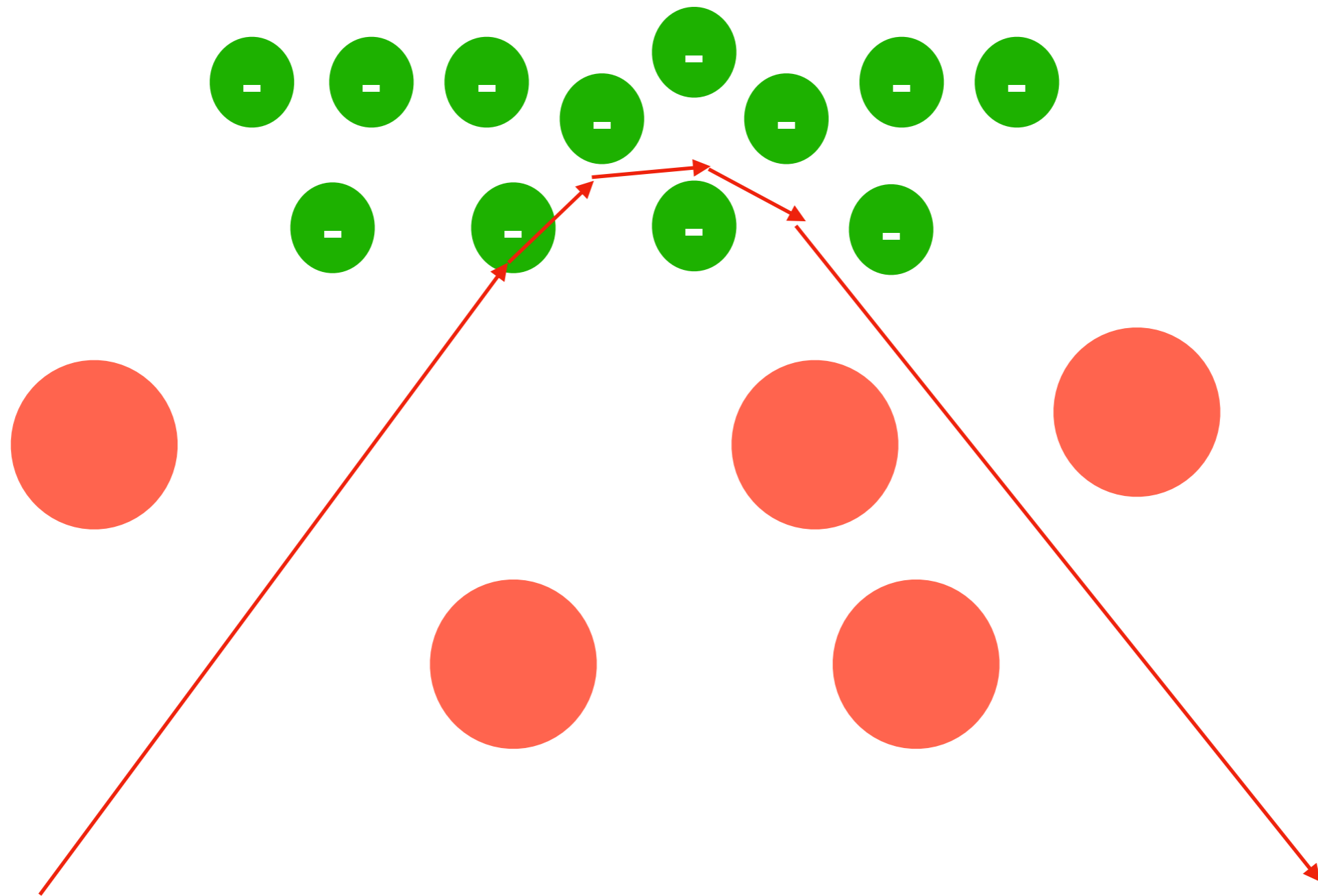


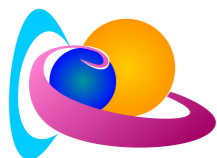
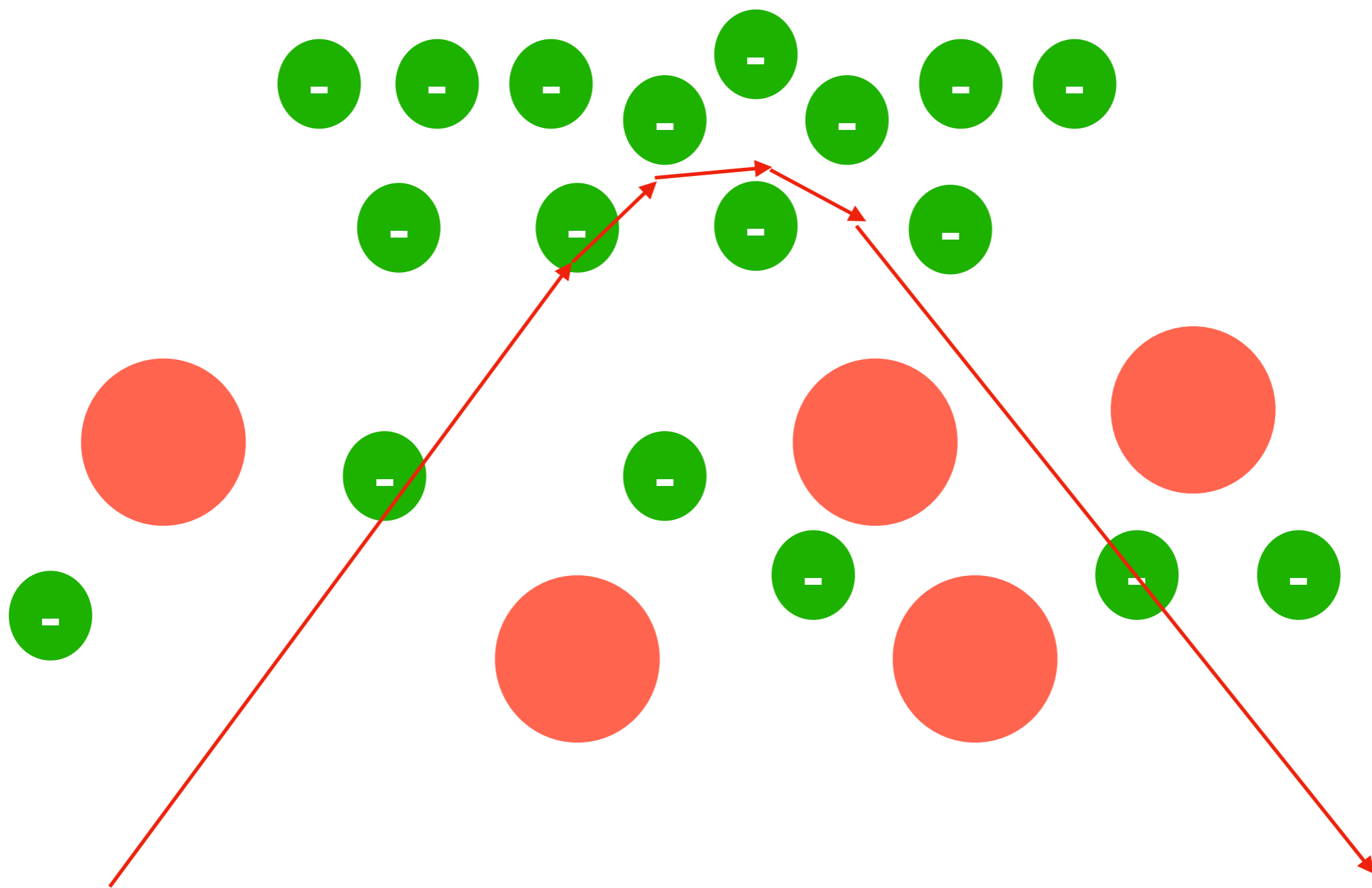
CME arrival



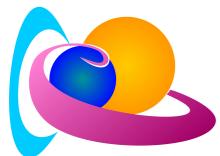
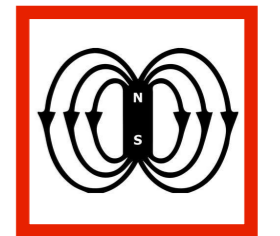
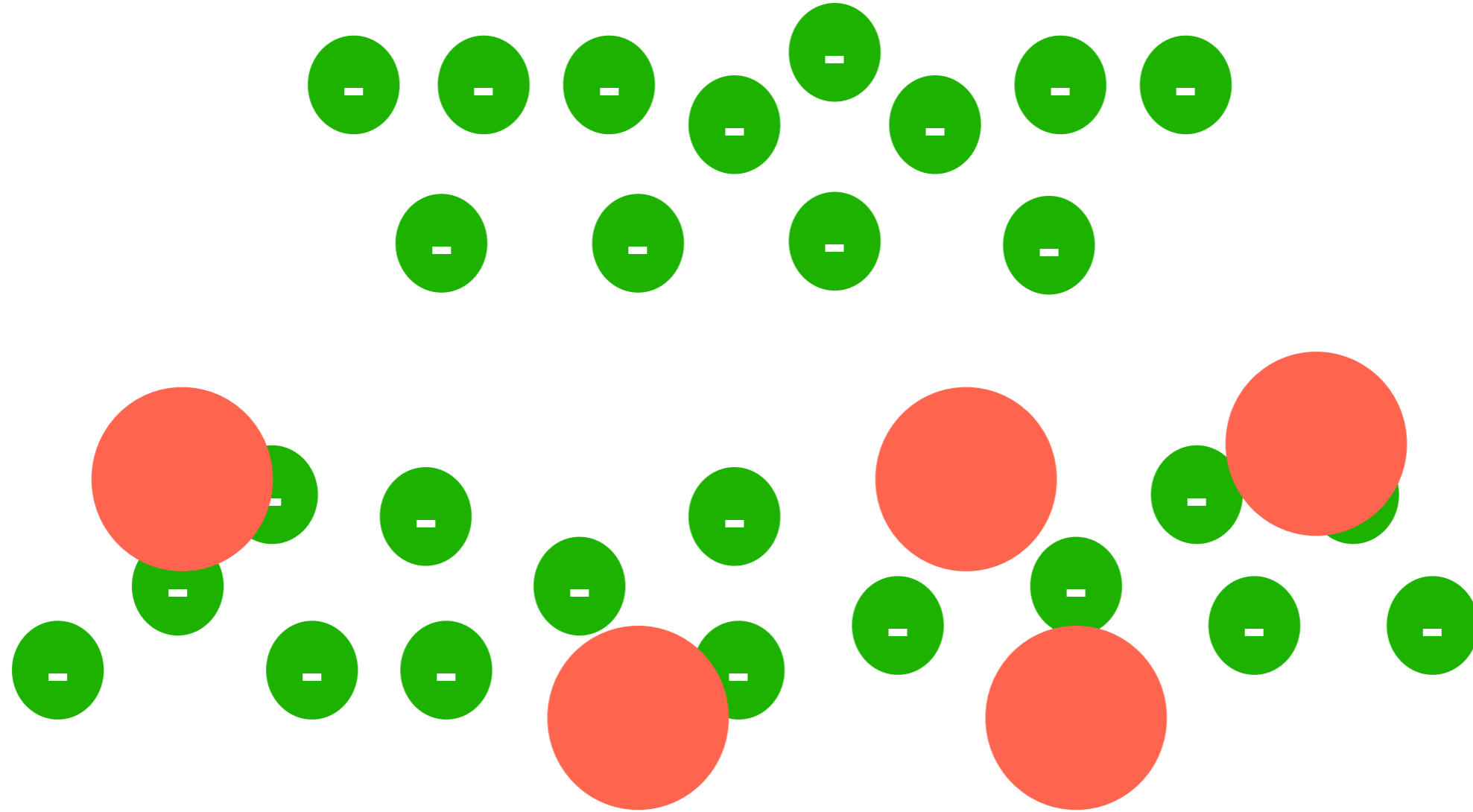




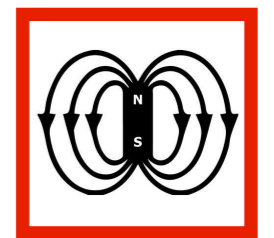
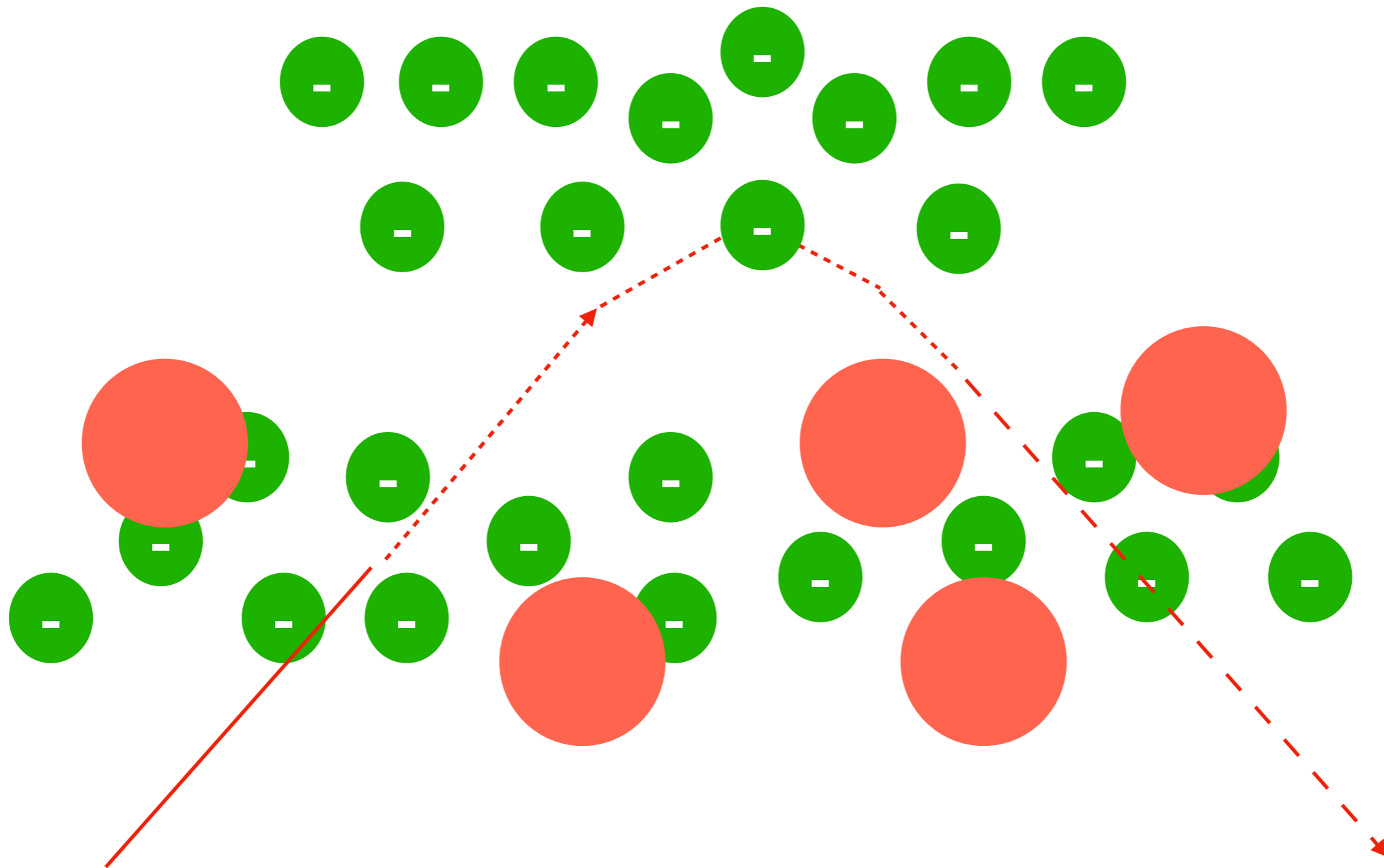




AA



AA



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=



10/10/2023
20:05 UTC

STATUS
ODC

MAIN

GNSS

RADIATION

HF COM

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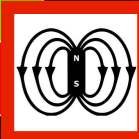
-24h -12h -6h -3h -1h -5m Submit 2023-04-23 18:50 now +5m +1h +3h +6h +12h +24h

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

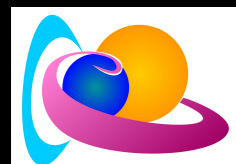
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
<u>Amplitude Scintillation</u>	0.5	0.8	2023-04-23 18:50	0.40	QUIET		0.40	QUIET
<u>Phase Scintillation</u>	0.4	0.7	2023-04-23 18:50	0.26	QUIET		0.26	QUIET
<u>Vertical TEC</u>	125	175	2023-04-23 18:50	124.06	QUIET		124.06	QUIET

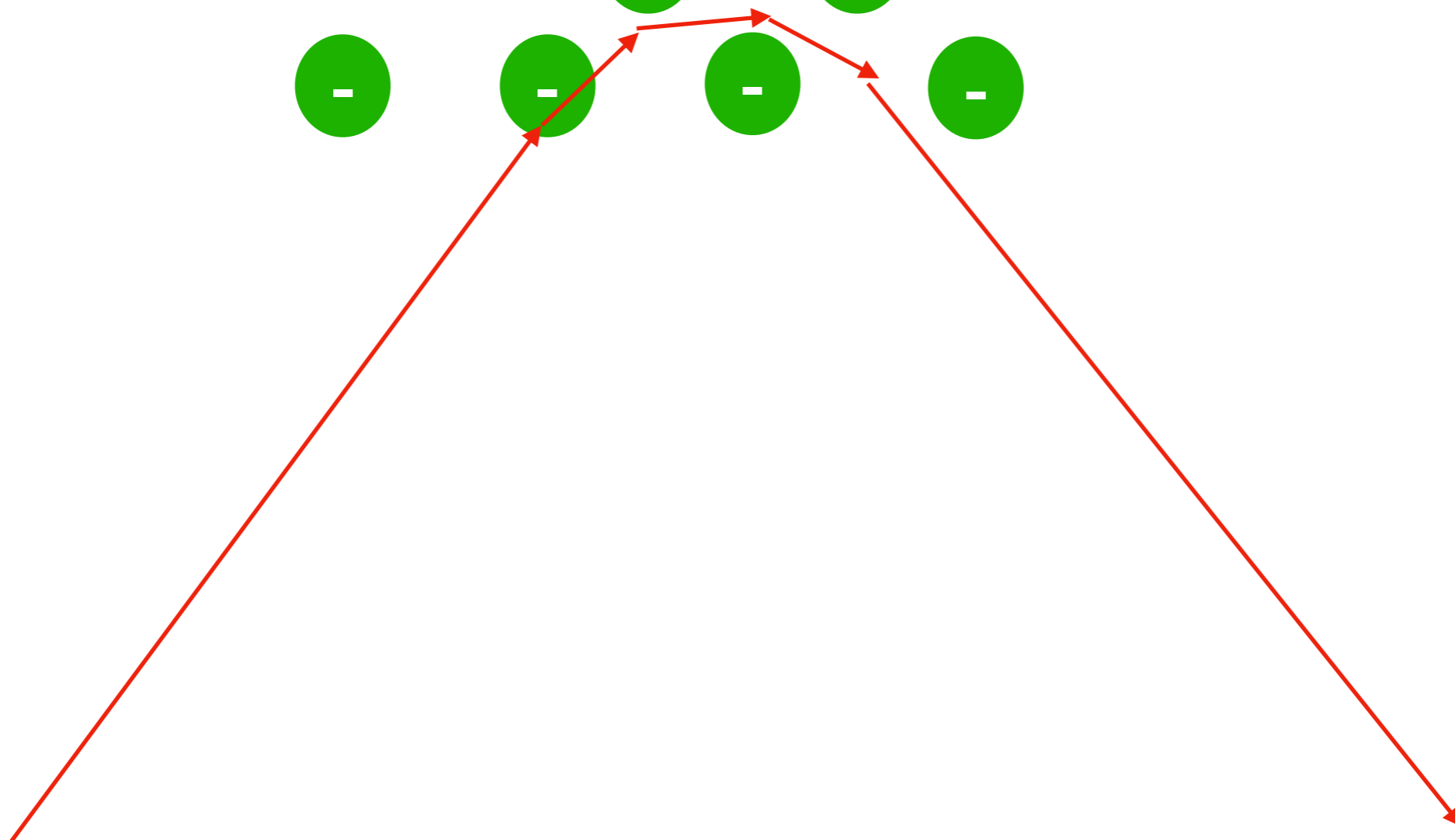
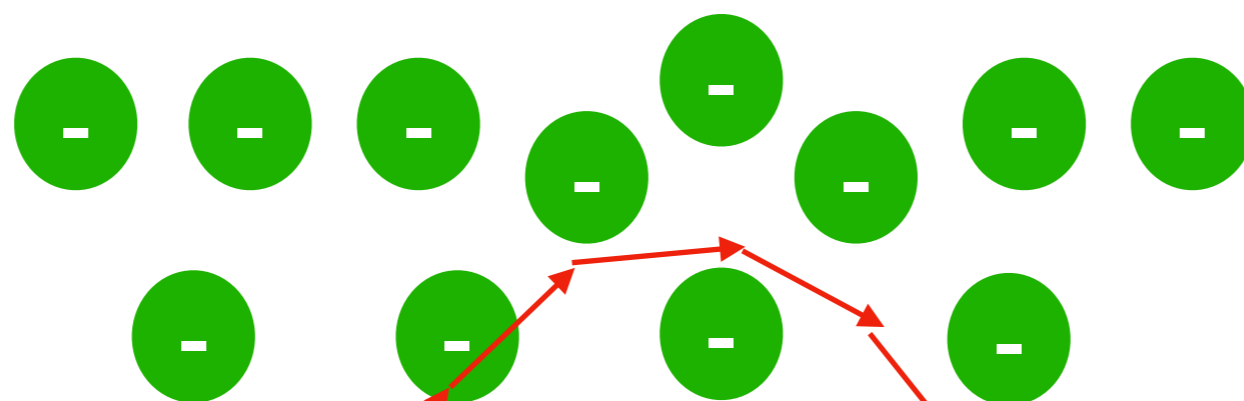
RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
<u>Effective Dose FL ≤ 460</u>	30	80	2023-04-23 18:50	0	QUIET		0	QUIET
<u>Effective Dose FL > 460</u>	/	80	2023-04-23 18:50	0	QUIET		0	QUIET

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

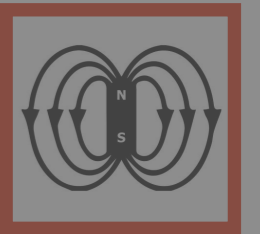
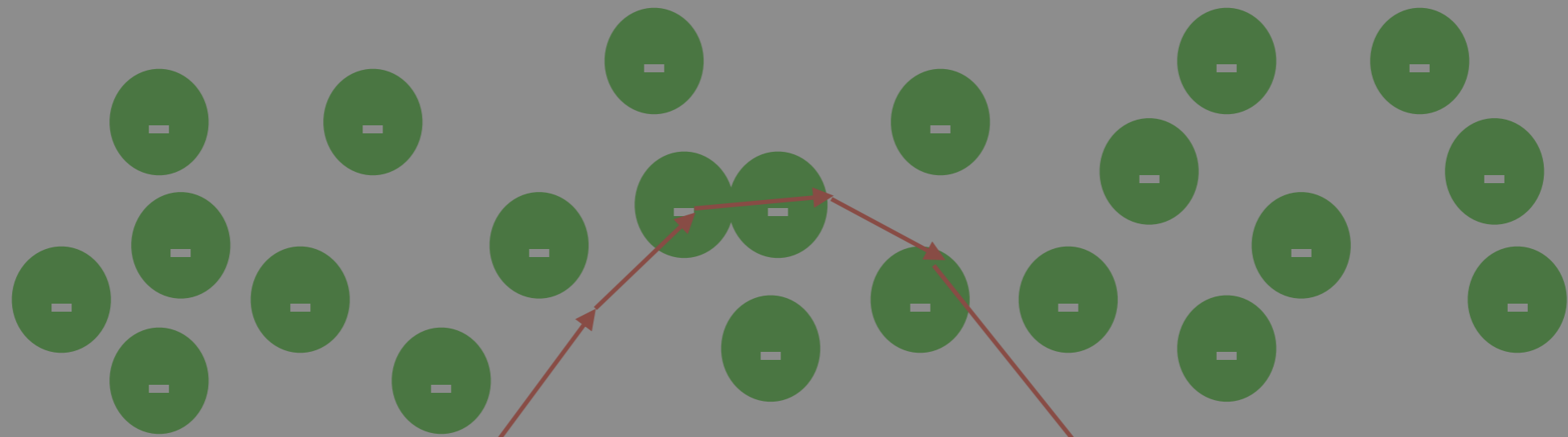


Sound alarm is triggered when MOD or SEV thresholds are exceeded or in case of data outages.

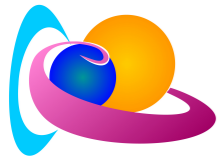
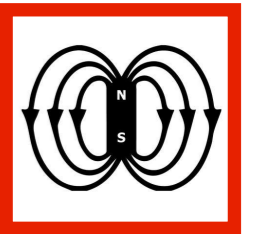
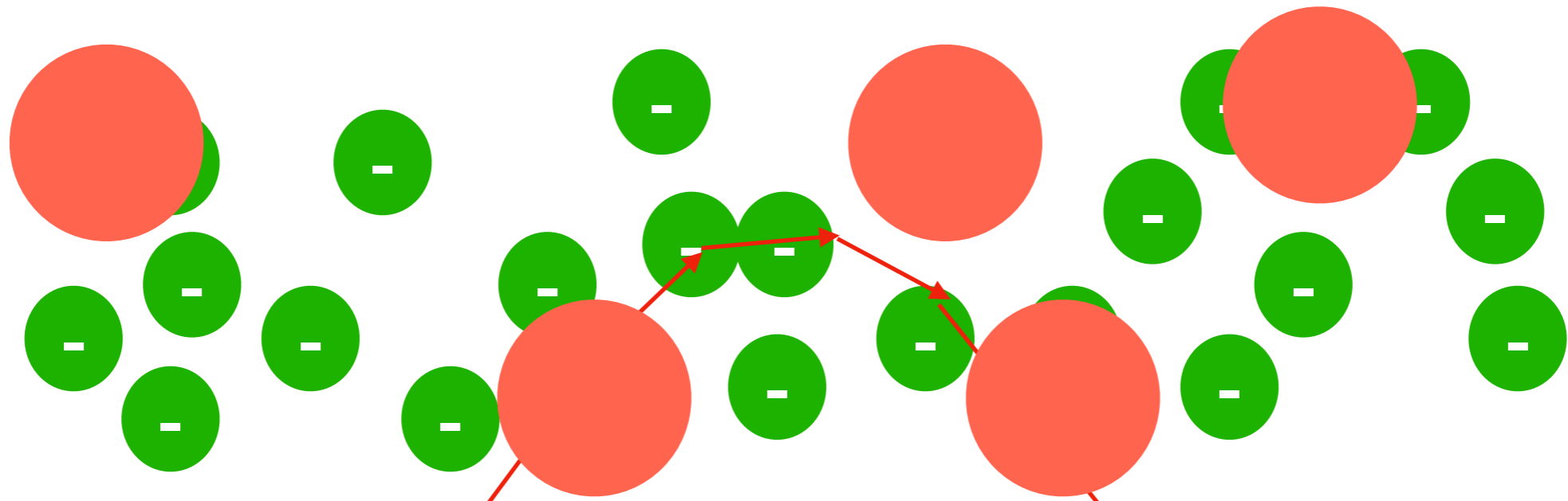




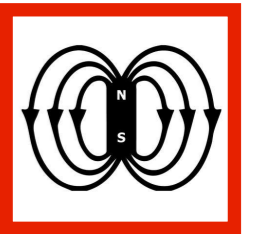
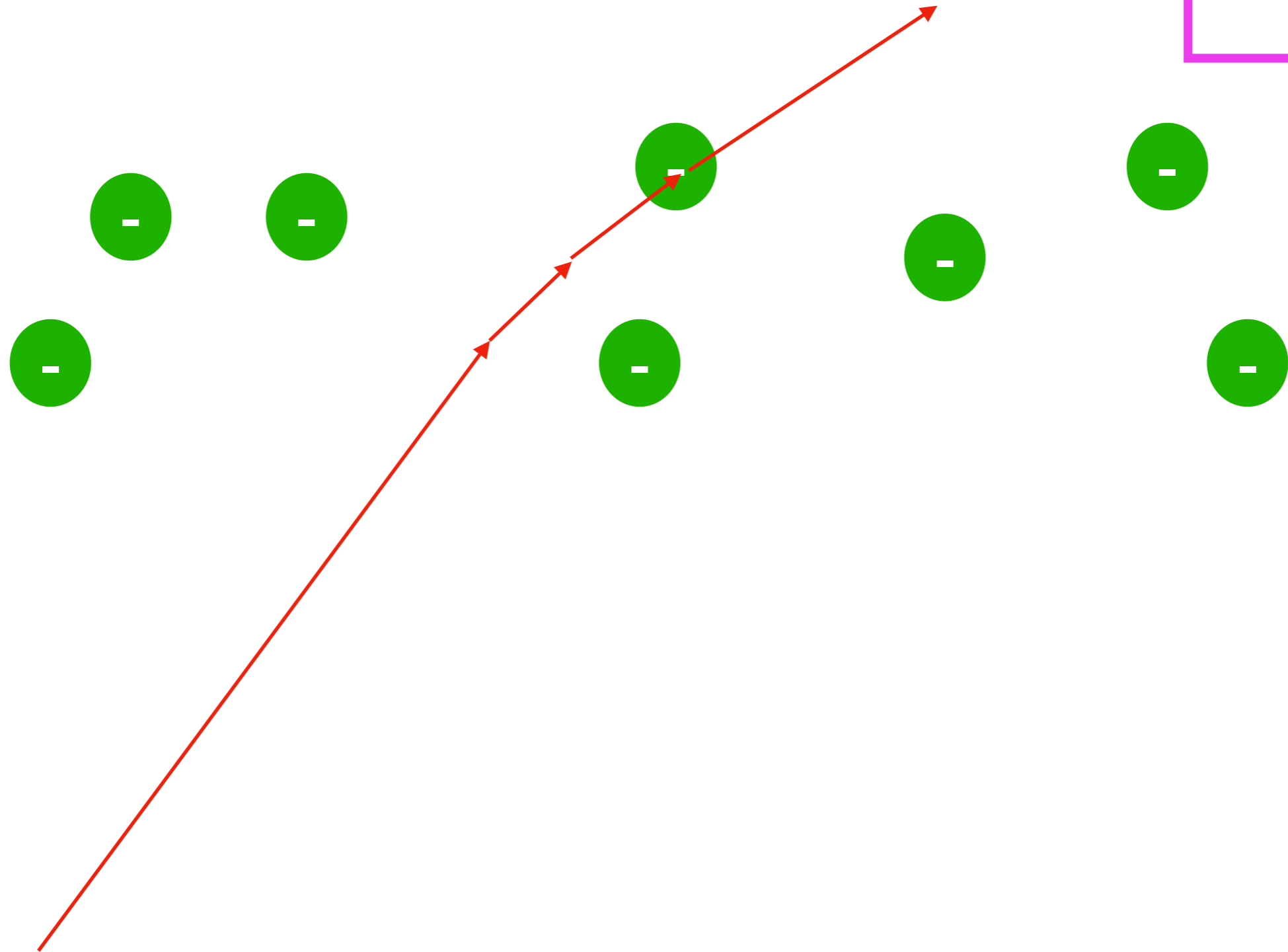
POSITIVE PHASE

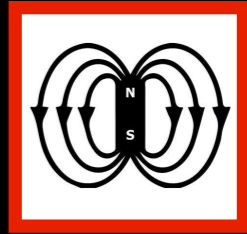


NEGATIVE PHASE



PSD





-24h -12h -6h -3h -1h -5m Submit 2023-04-23 20:30 now +5m +1h +3h +6h +12h +24h

FoF2/MUF DASHBOARD on 2023-04-23 20:30 UTC

See worldmap with latest ionosondes data ([here](#)) Find EU maps ([here](#))

10/10/2023
20:18 UTC

STATUS
ODC

MAIN

GNSS

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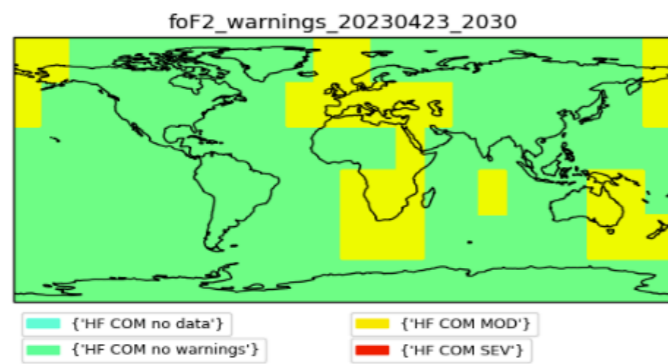
RWC

Contact

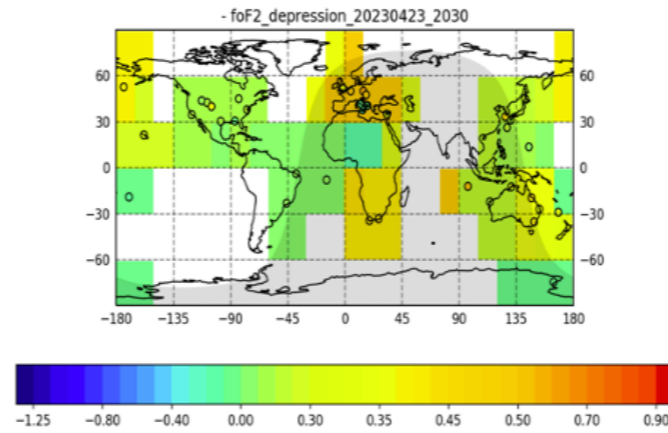
Mute status

OnCall Report

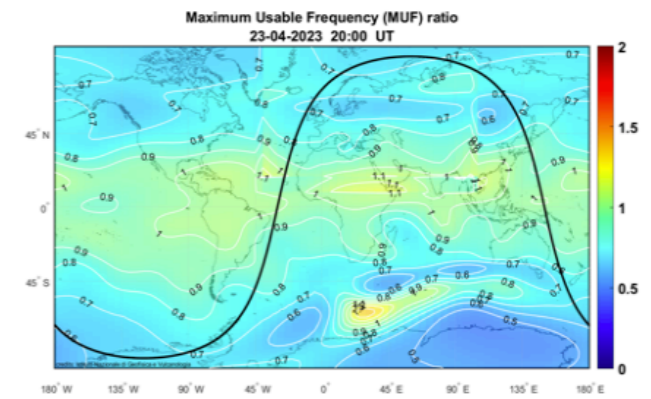
Post-Storm Depression: foF2 Warnings (SRCPAS)



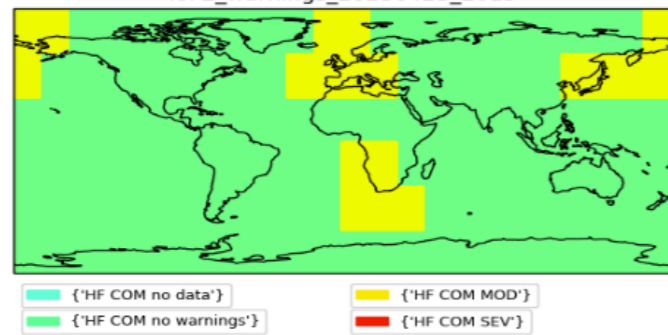
Post-Storm Depression: foF2 Ratio NowCast (SRCPAS)



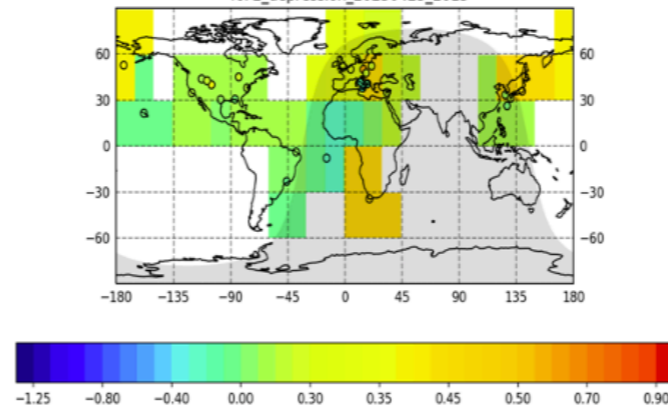
Post-Storm Depression: MUF Ratio NowCast (INGV)



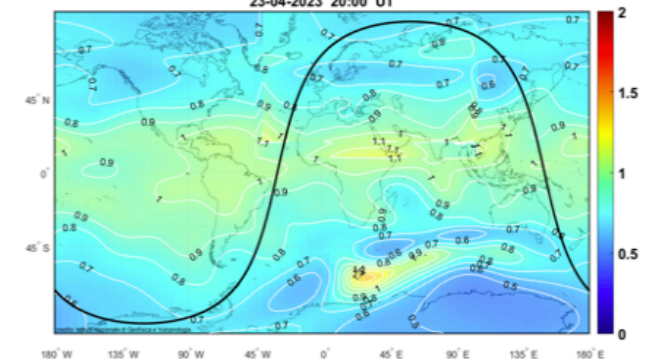
foF2_warnings_20230423_2015



-foF2_depression_20230423_2015



Maximum Usable Frequency (MUF) ratio 23-04-2023 20:00 UT



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

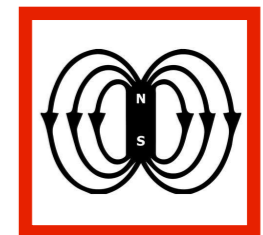
FCST SWX +12 HR: 24/0900Z NOT AVBL

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

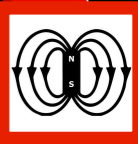


- 10/10/2023 20:34 UTC
- STATUS ODC
- MAIN
- GNSS
- RADIATION
- HF COM
- ARCHIVE
- Advisory
- Daily Brief
- Data
- Procedures
- Portfolio
- ICAO Docs
- RWC
- Contact
- Mute status

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

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

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

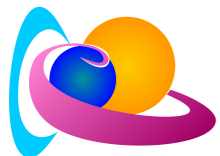
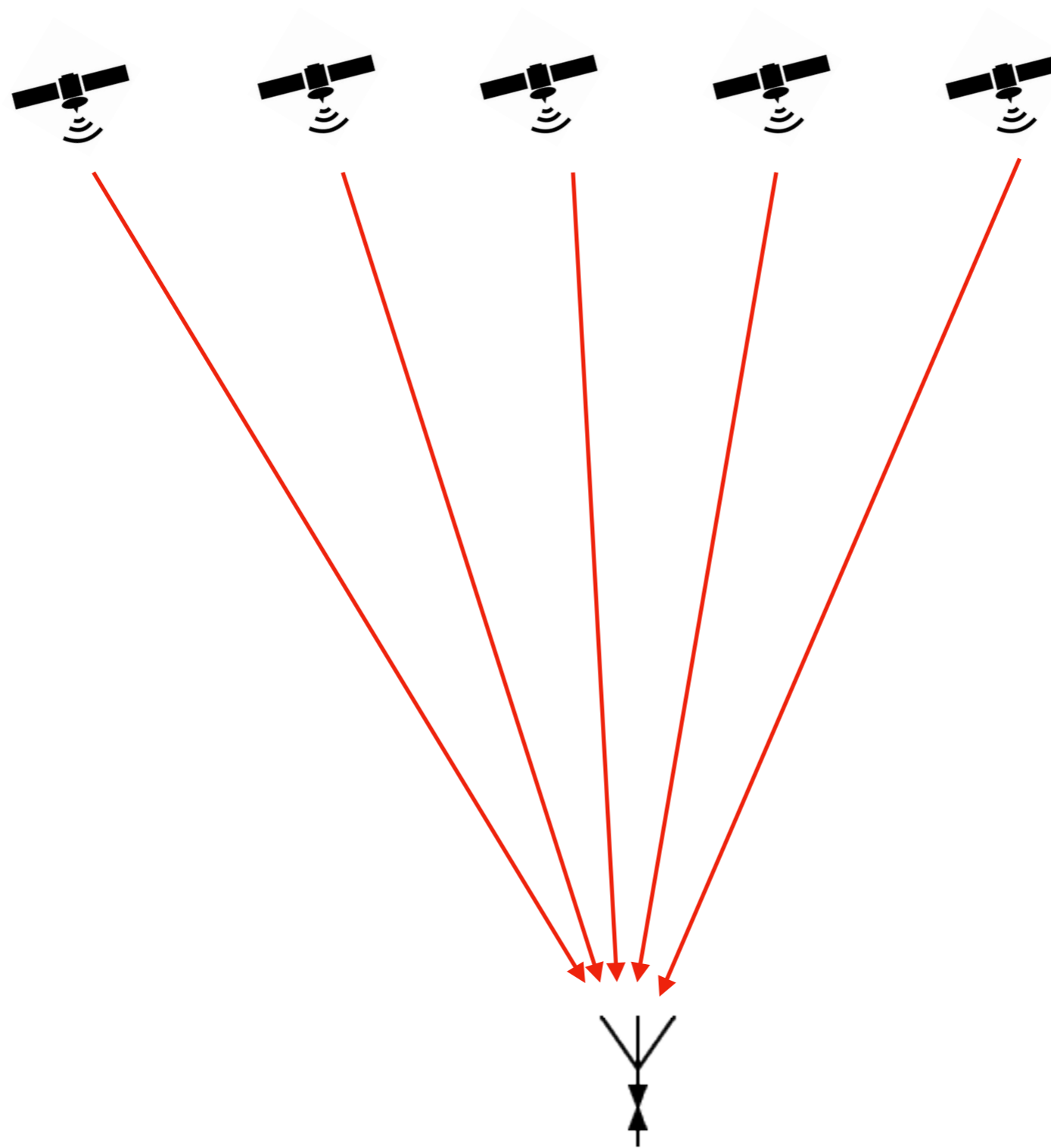


RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
<u>Effective Dose FL ≤ 460</u>	30	80	2023-04-23 20:35	0	QUIET	🔔	0	QUIET
<u>Effective Dose FL > 460</u>	/	80	2023-04-23 20:35	0	QUIET	🔔	0	QUIET

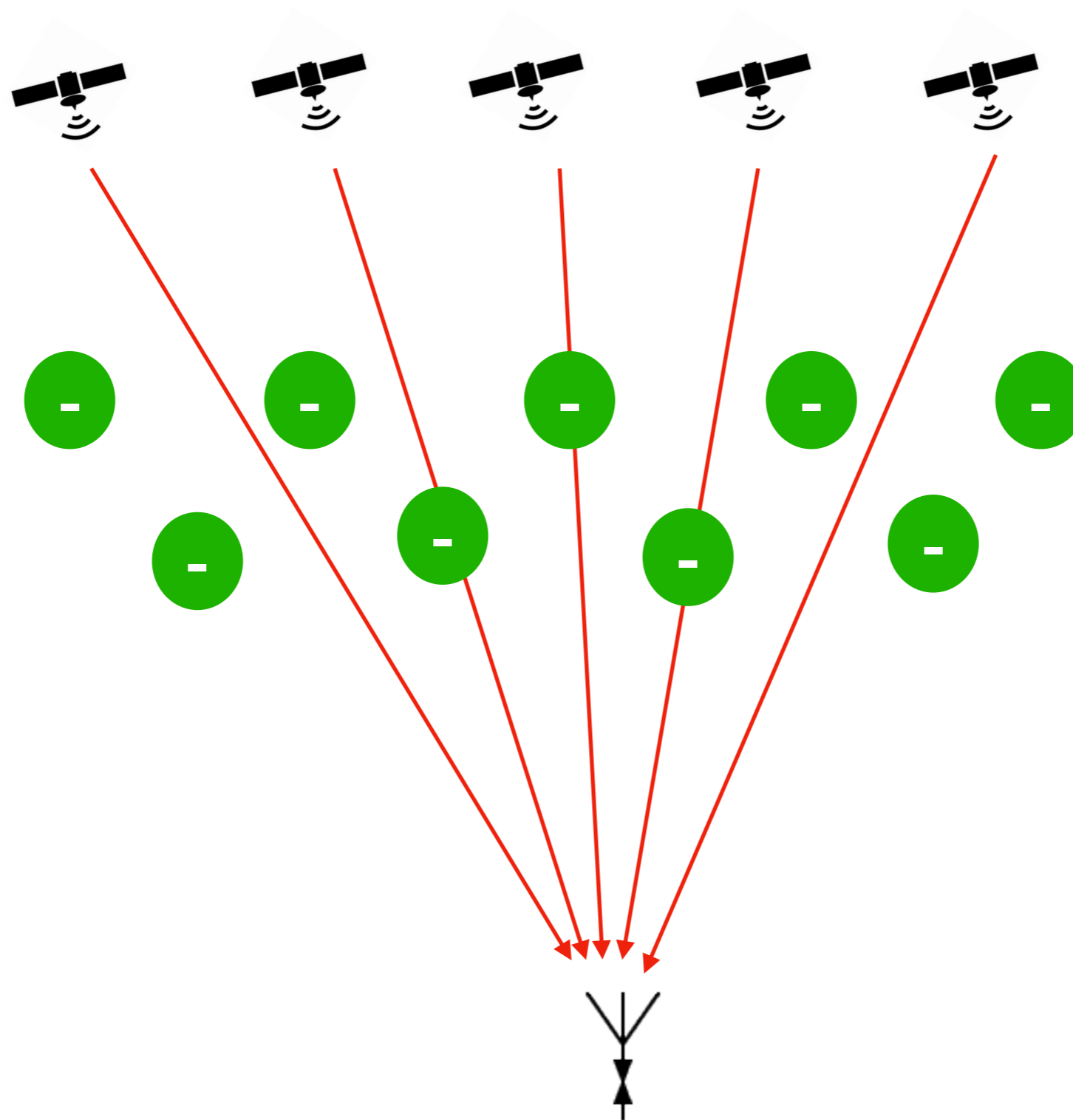
HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
<u>Auroral Absorption (AA)</u>	8	9	2023-04-23 20:36	8.0	MODERATE	🔔	8.0	MODERATE
<u>Polar Cap Absorption (PCA)</u>	2	5	2023-04-23 20:35	1.97	QUIET	🔔	4.64	MODERATE
<u>Shortwave Fadeout (SWF)</u>	x1.0	x10.0	2023-04-23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

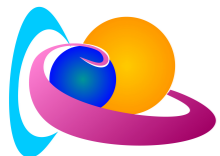
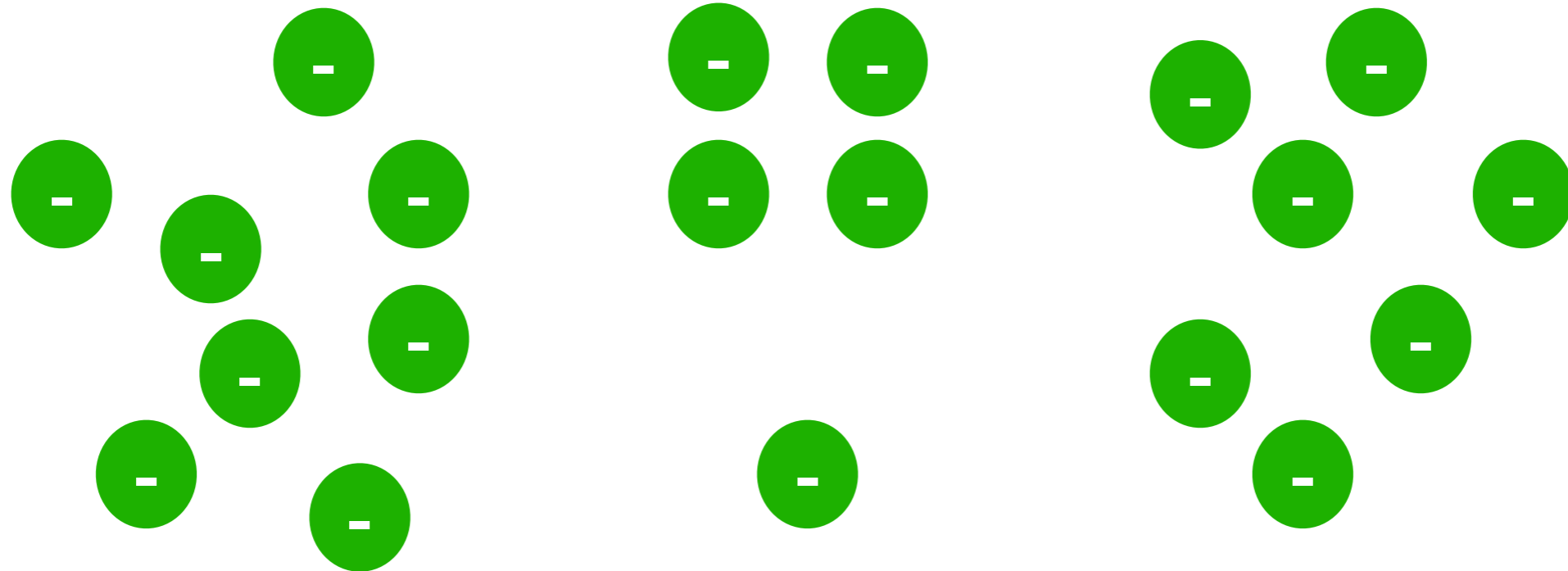
SCINTILLATION



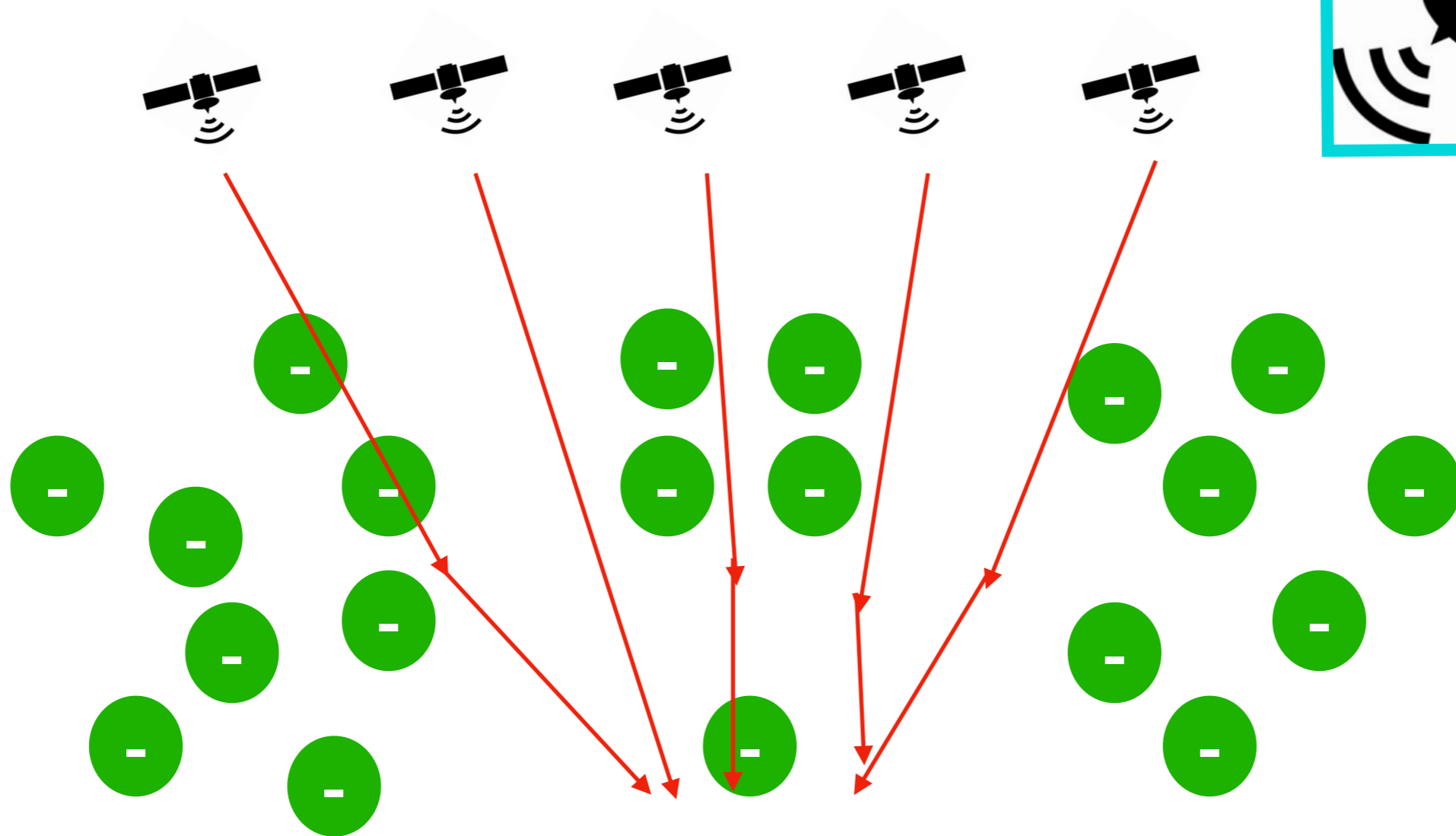
SCINTILLATION



SCINTILLATION



SCINTILLATION

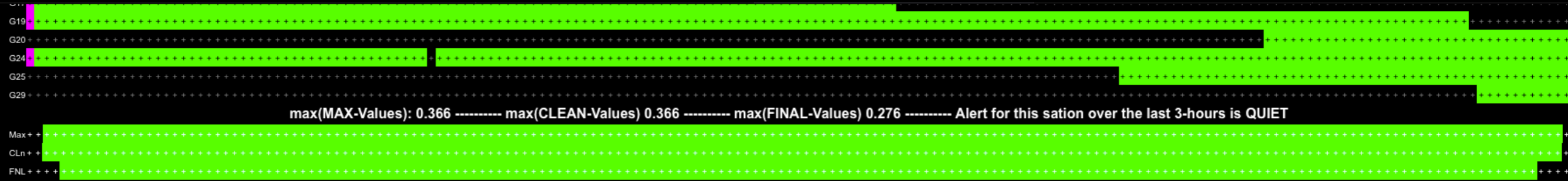


April 23, 20:36 UT



10/10/2023
20:36 UTC

STATUS
ODC



MAIN

DLR STATION MSTE (#satellite=16)

From 2023-Apr-23 17:36 To 2023-Apr-23 20:36

GNSS

RADIATION

HF COM

ARCHIVE

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Portfolio

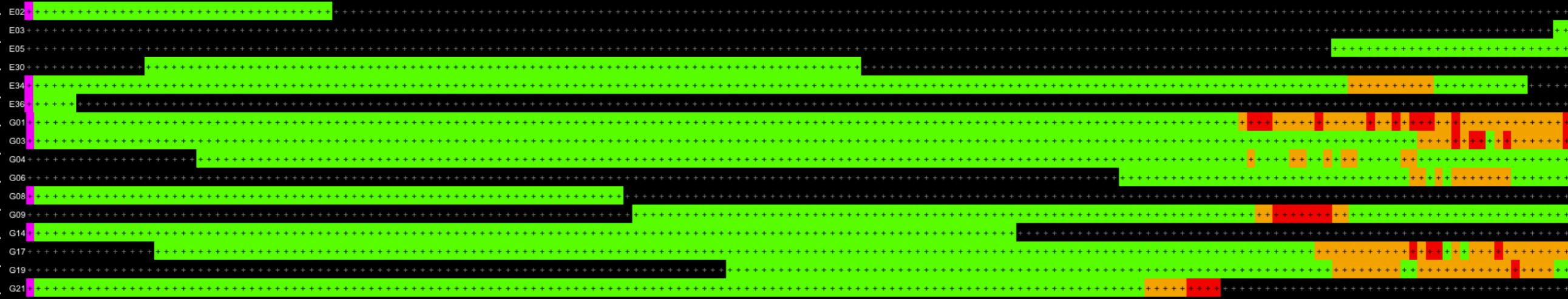
ICAO Docs

RWC

Contact

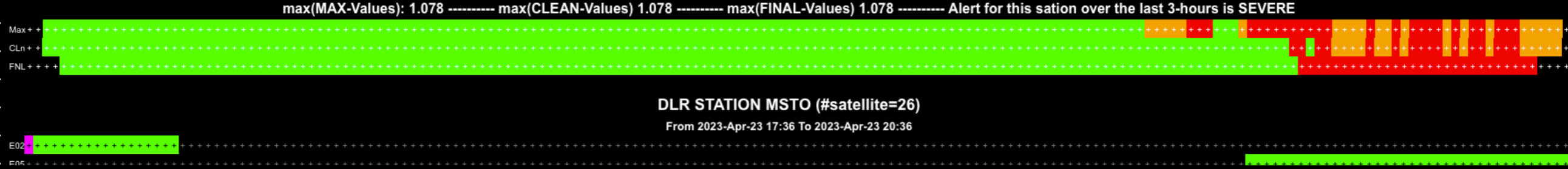
Mute status

OnCall Report

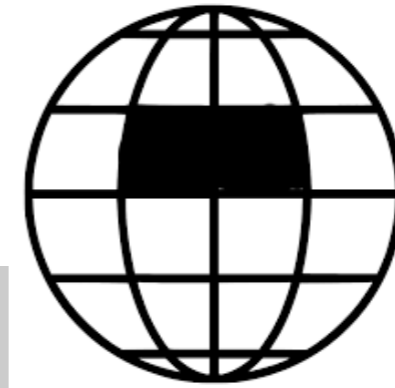


DLR STATION MSTO (#satellite=26)

From 2023-Apr-23 17:36 To 2023-Apr-23 20:36



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.

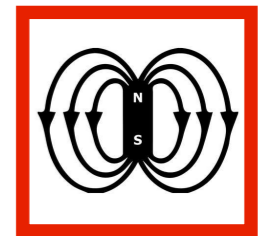
NXT ADVISORY: WILL BE ISSUED BY 20230424/0229Z=

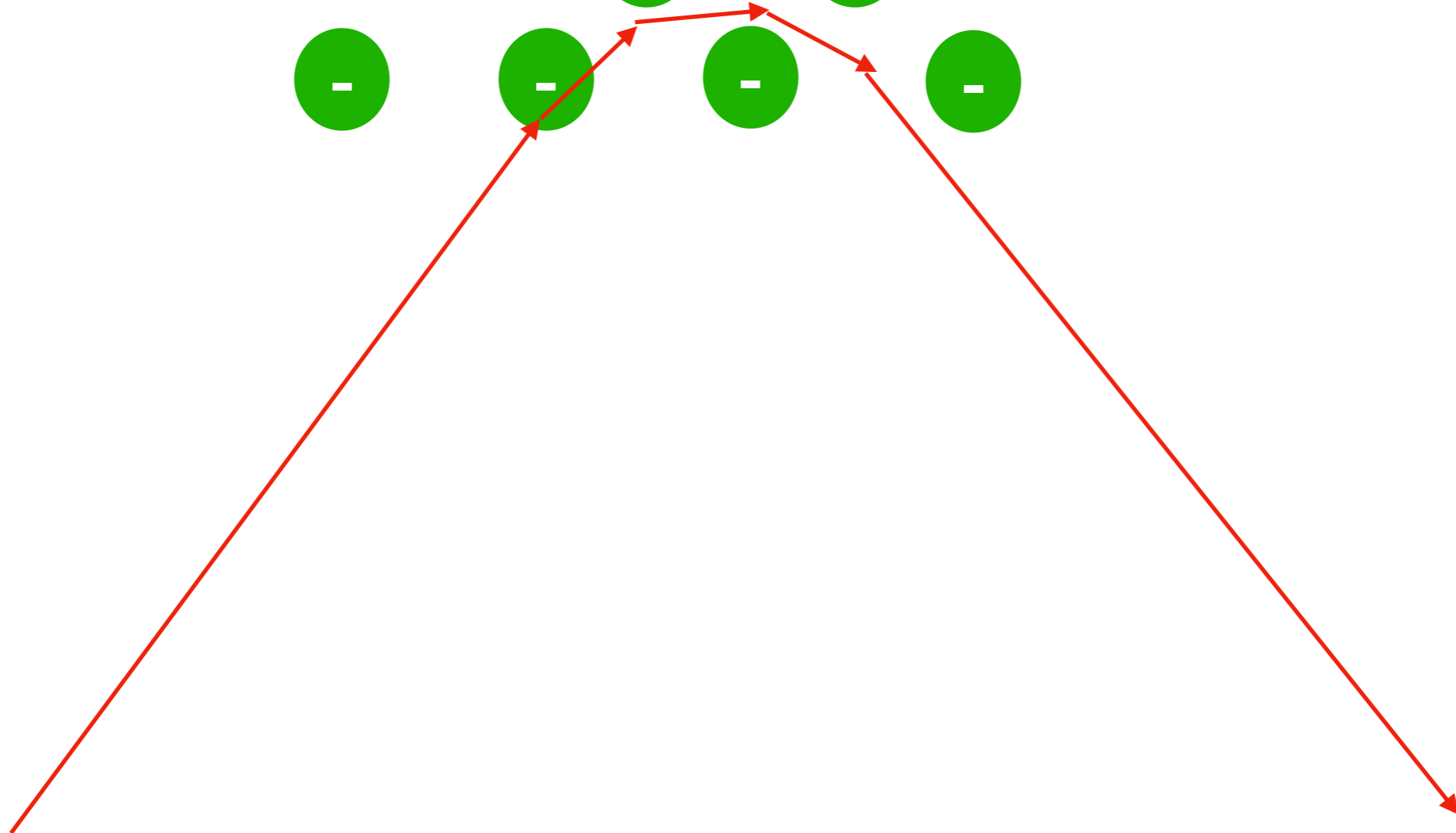
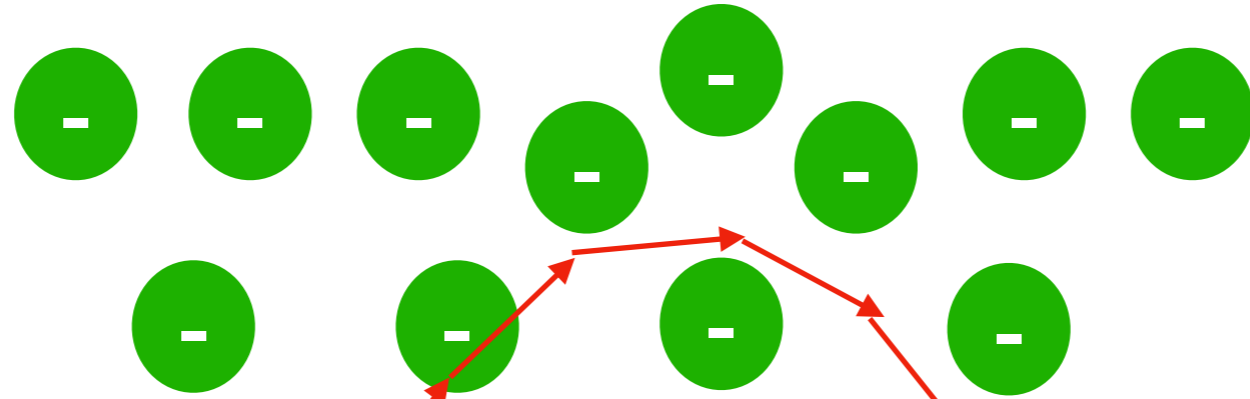
You made it until the end of this presentation!
Well done.

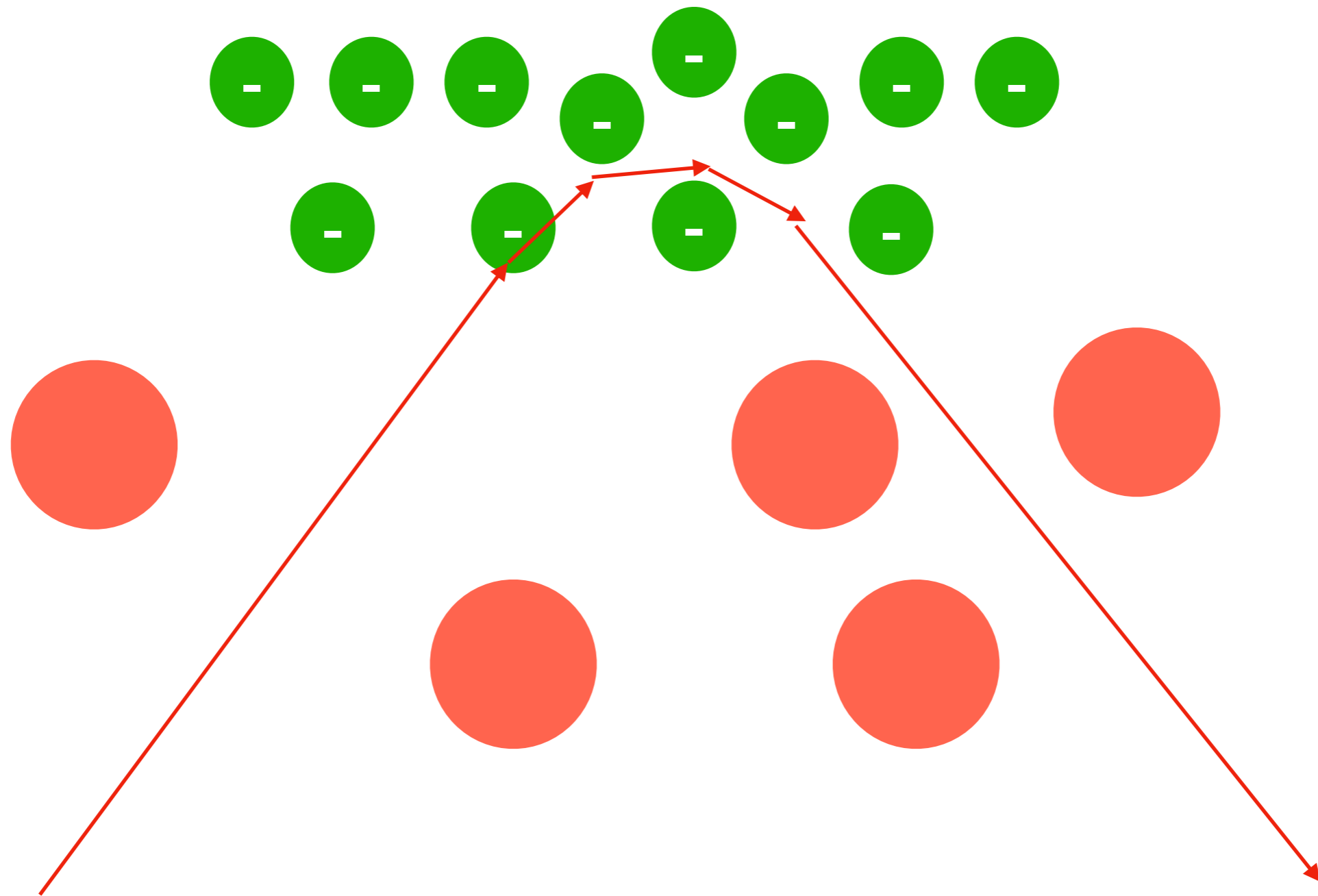
The PECASUS operator on duty at that time
was not done yet. Trouble in the ionosphere
continues until 4 days after $K_p=6$

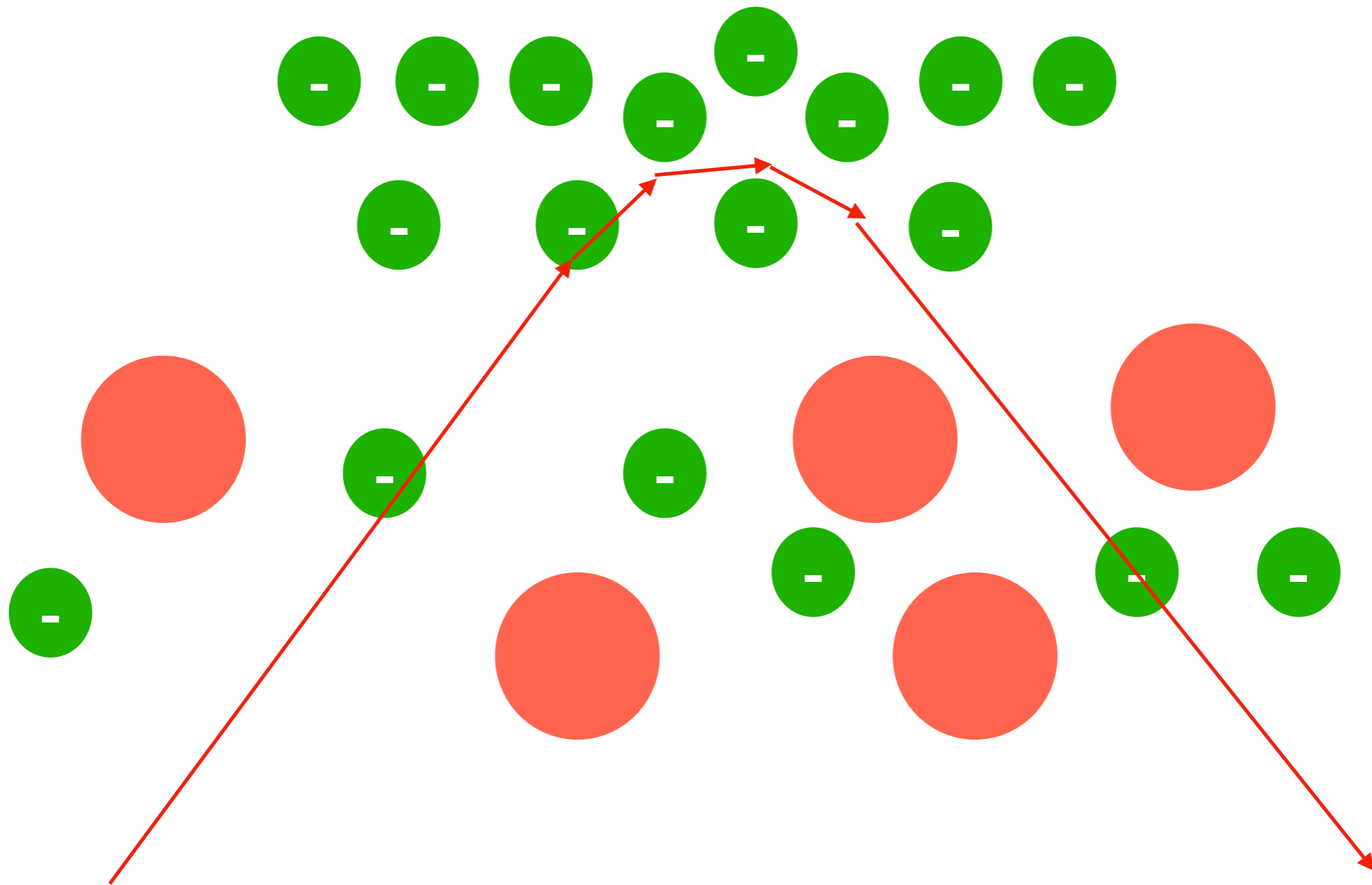


Bis-slides:
What about SWF?

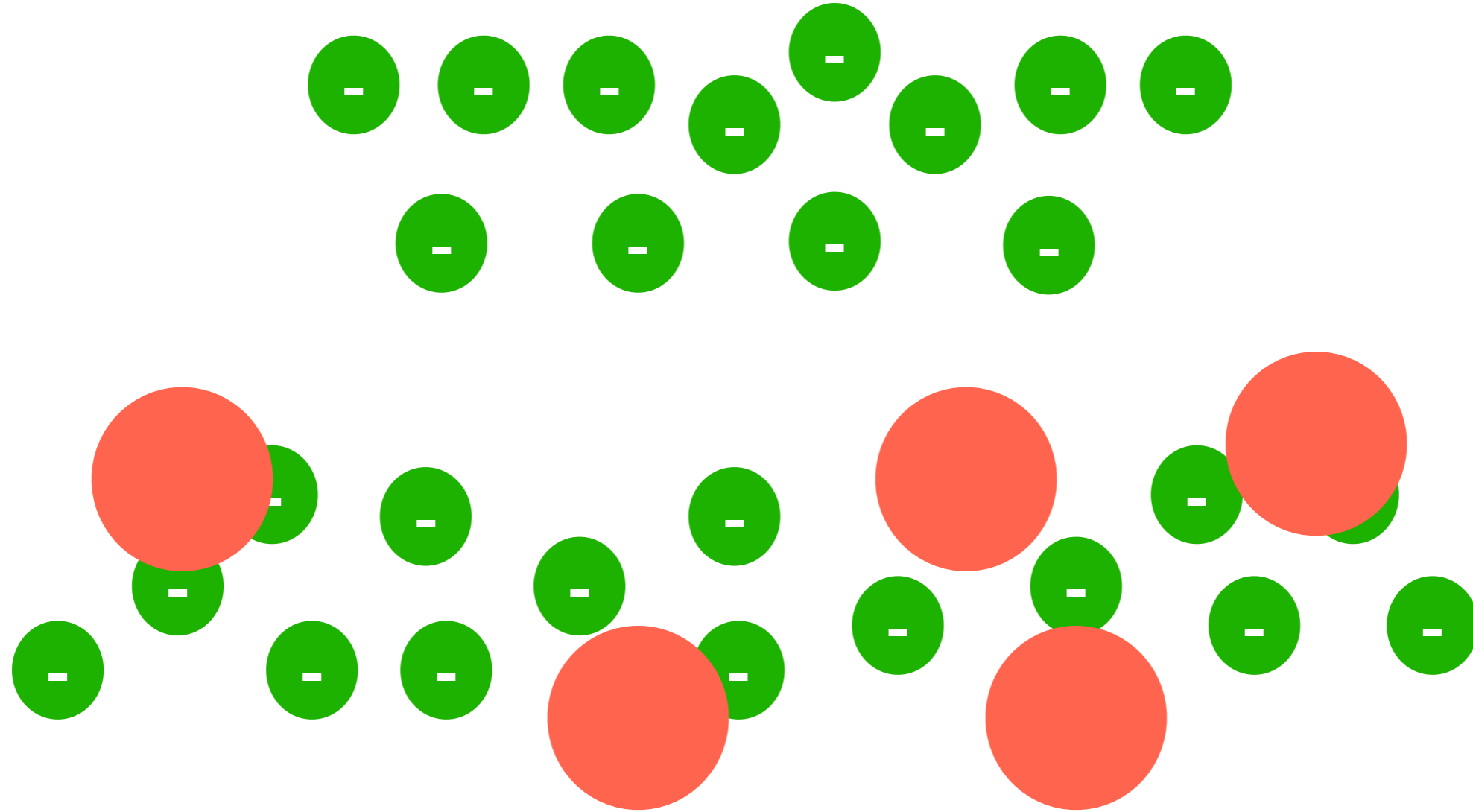




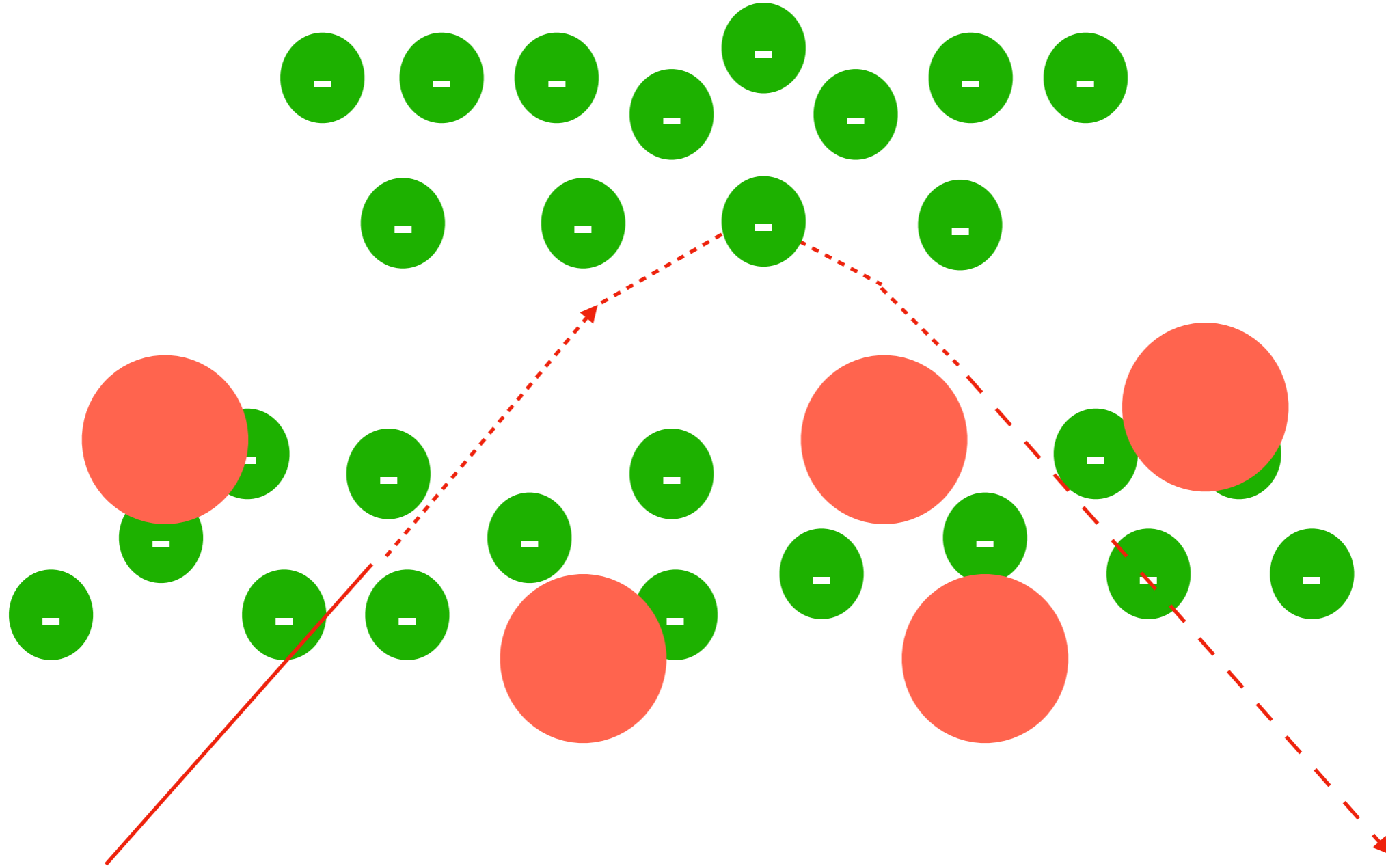




SWF



SWF

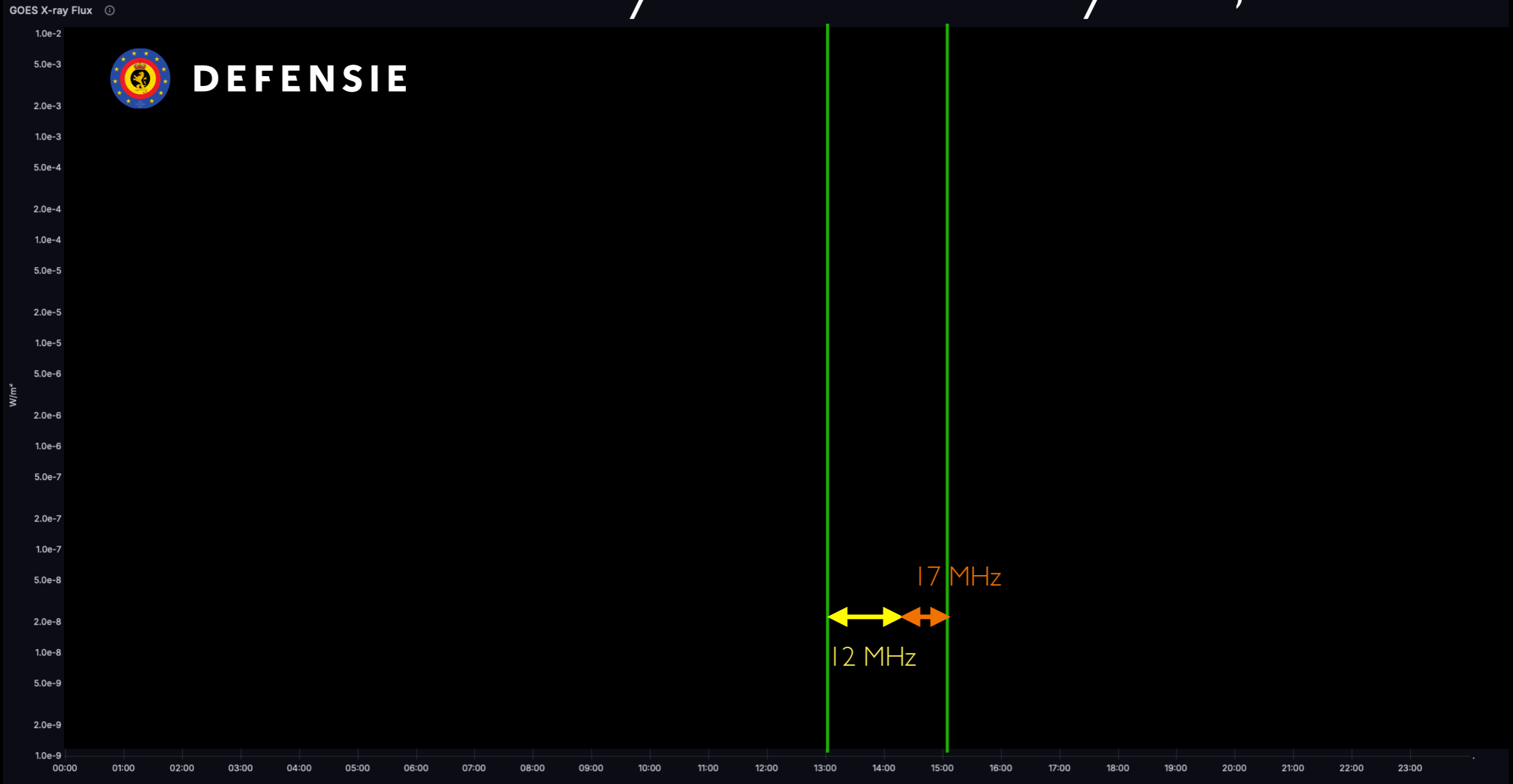


After Mother's day storm - May 15, 2024

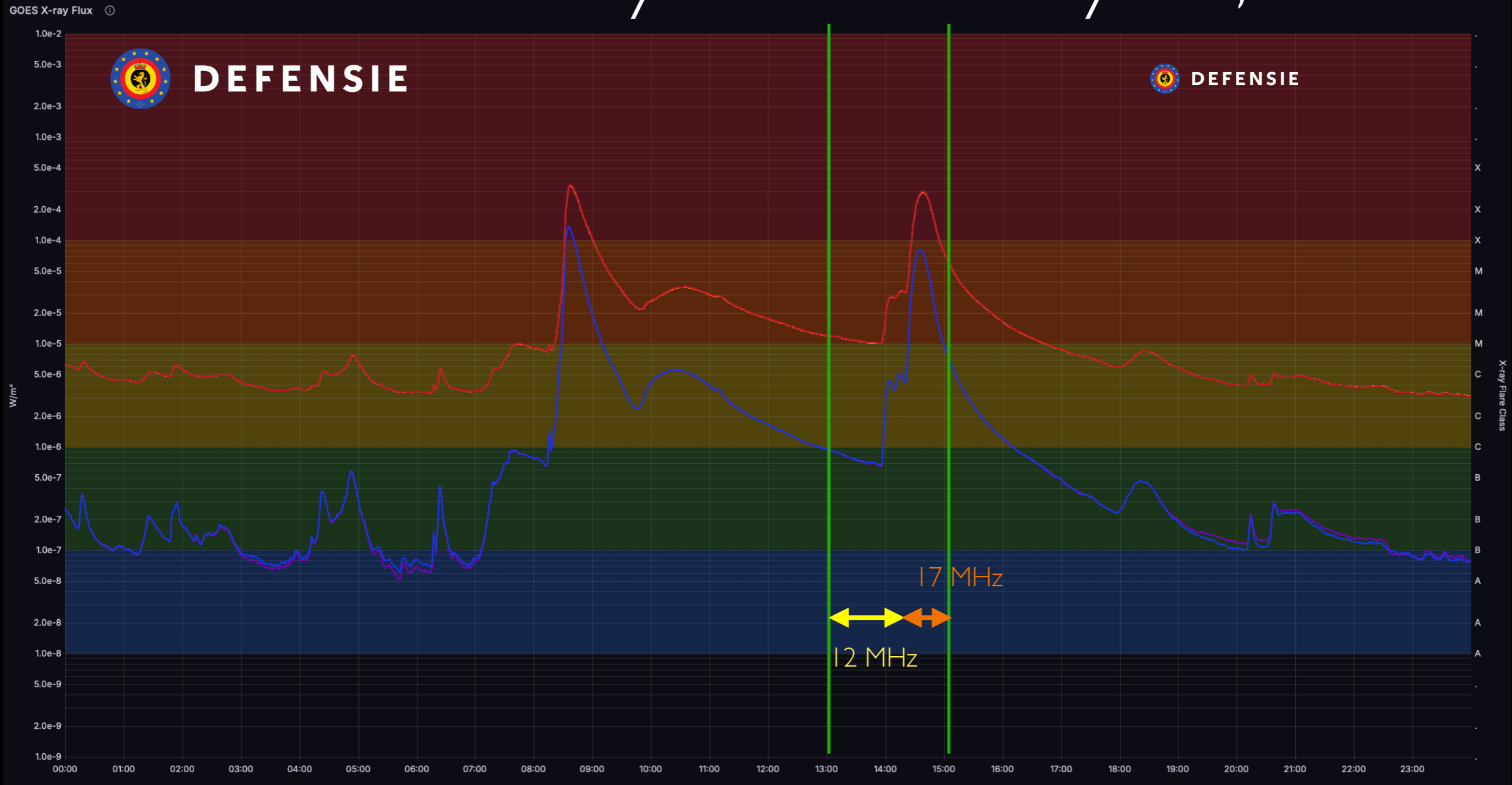


DEFENSIE

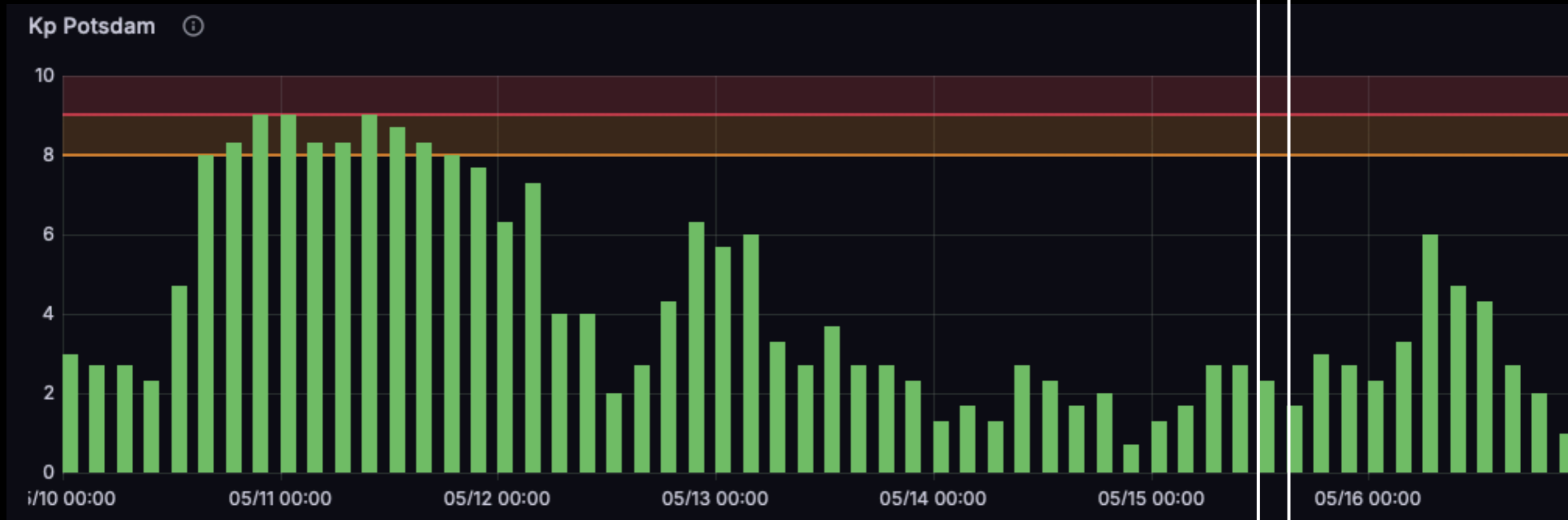
After Mother's day storm - May 15, 2024



After Mother's day storm - May 15, 2024

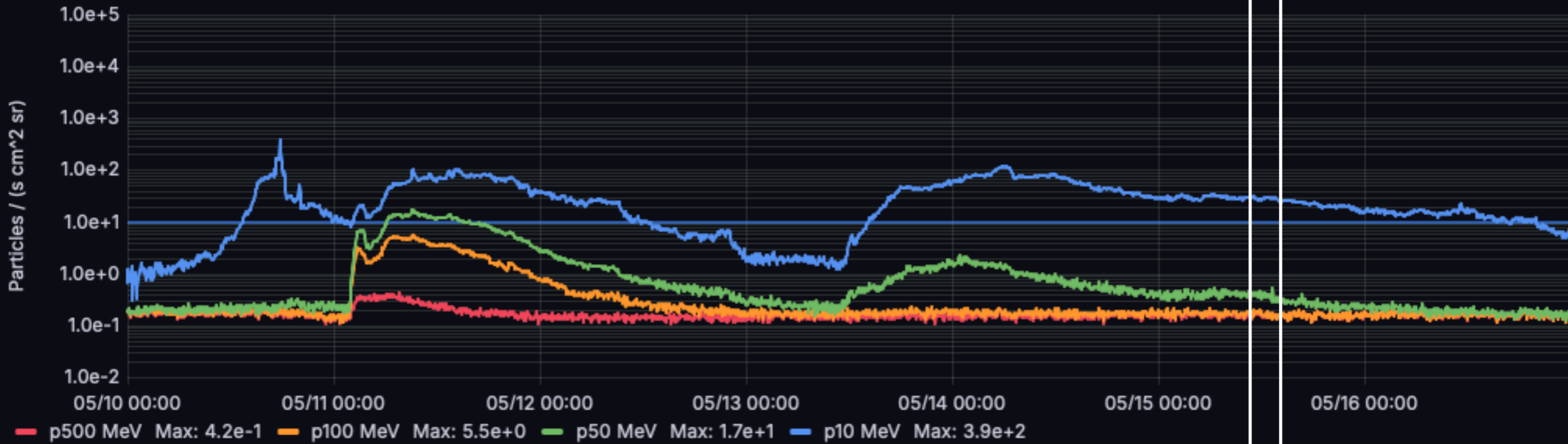


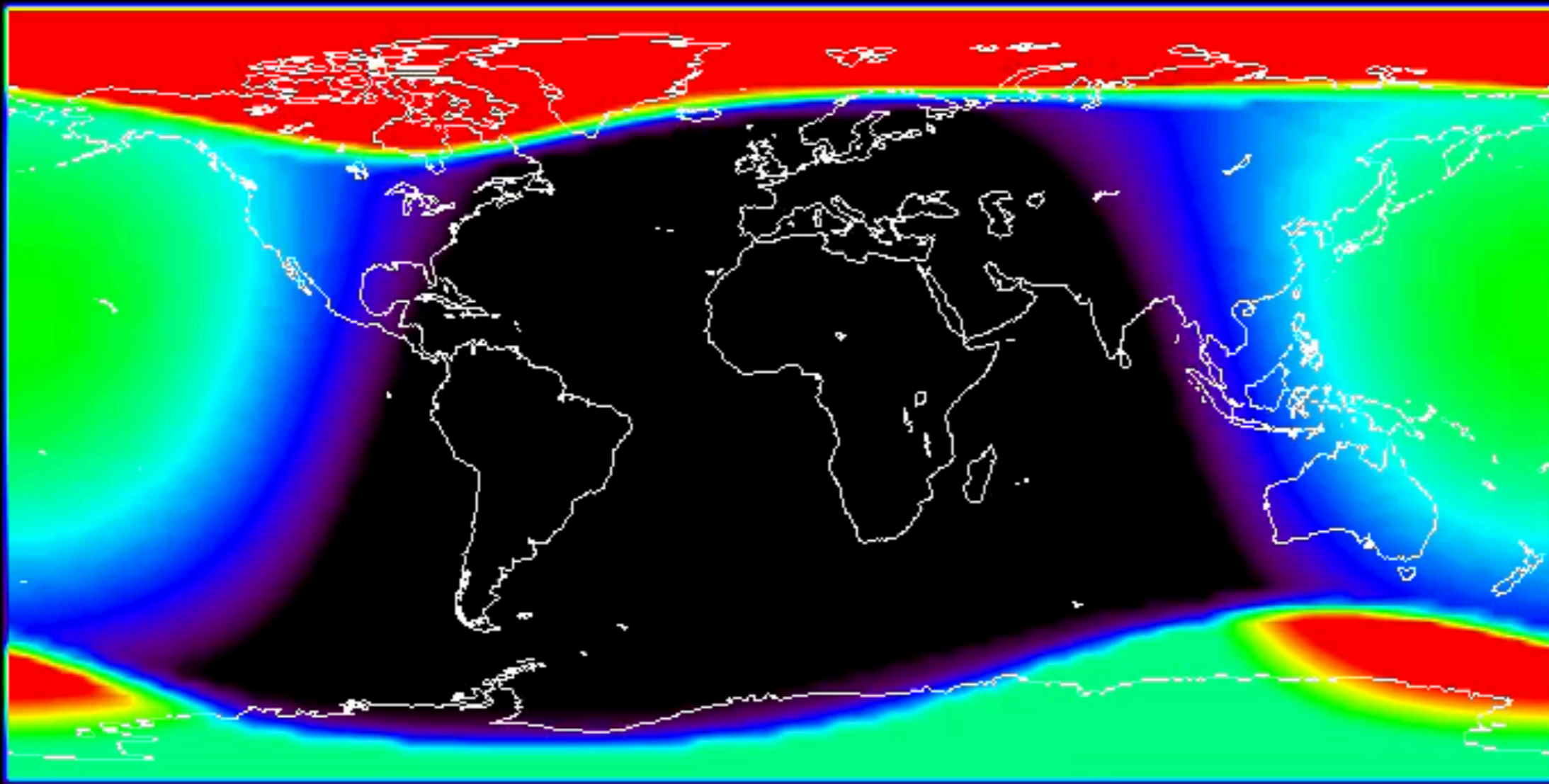
After Mother's day storm - May 15, 2024



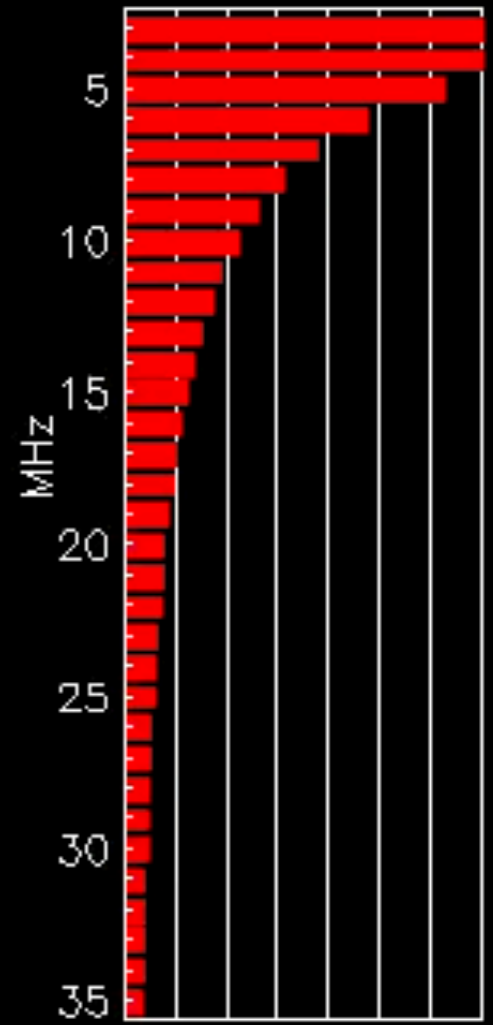
After Mother's day storm - May 15, 2024

GOES-16 Proton Flux ⓘ





Attenuation (Maximum Absorption)



Highest Frequency Affected by 1dB Absorption



Estimated Recovery Time
 High Latitude Protons :
 5 HRS 47 MINS
 Mid/Low Latitude X-rays :
 No Estimate

Attenuation (Maximum Absorption)
 dB

Elevated X-ray flux
 Product Valid At : 2024-05-15 00:00 UTC

Minor Proton Flux
 NOAA/SWPC Boulder, CO USA