Space weather risks: the military user’s perspective

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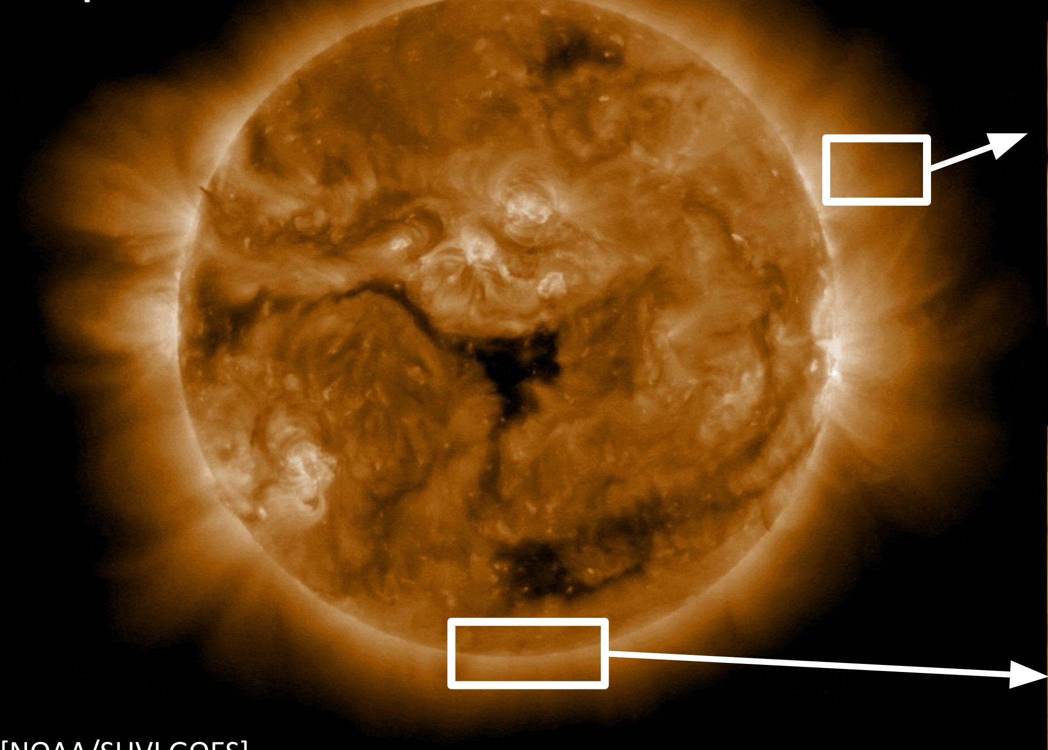
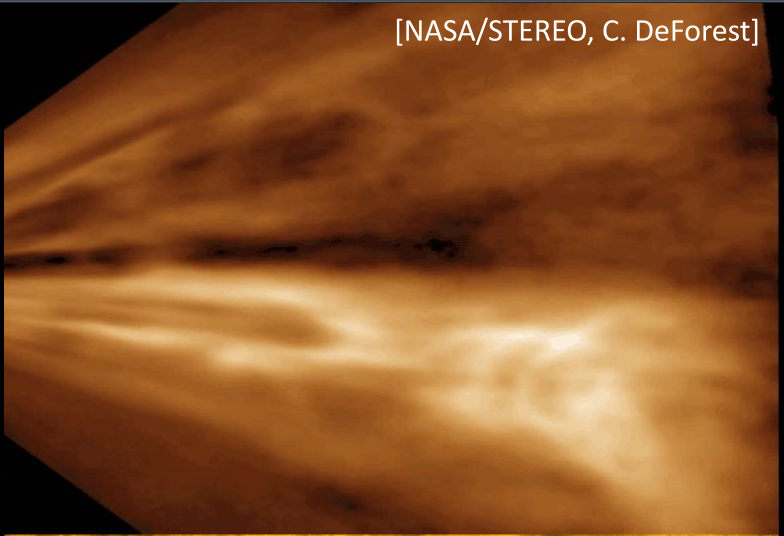
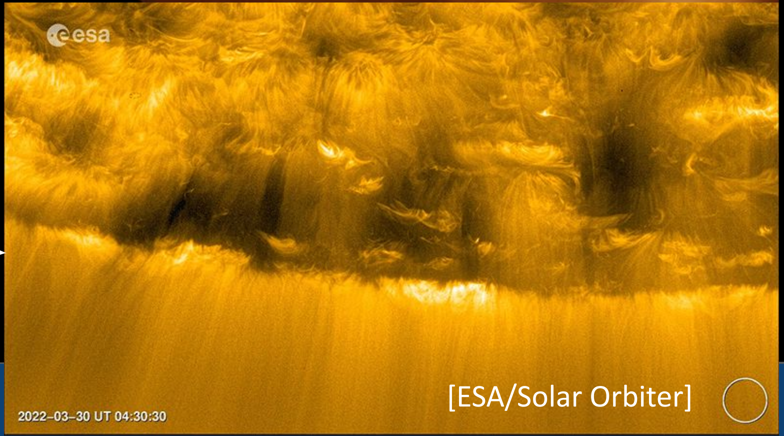
Space weather: the solar wind



[NOAA/SUVI GOES]

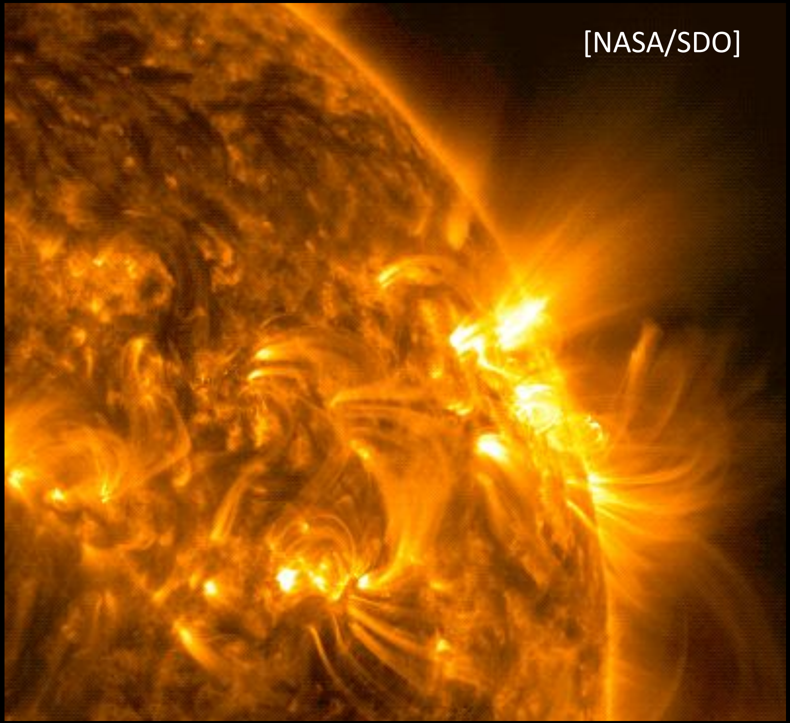


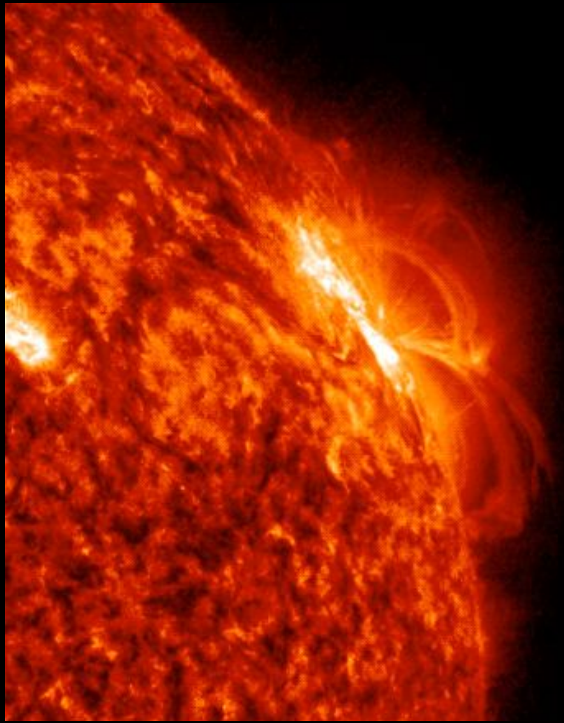
[NASA/STEREO, C. DeForest]



[ESA/Solar Orbiter]

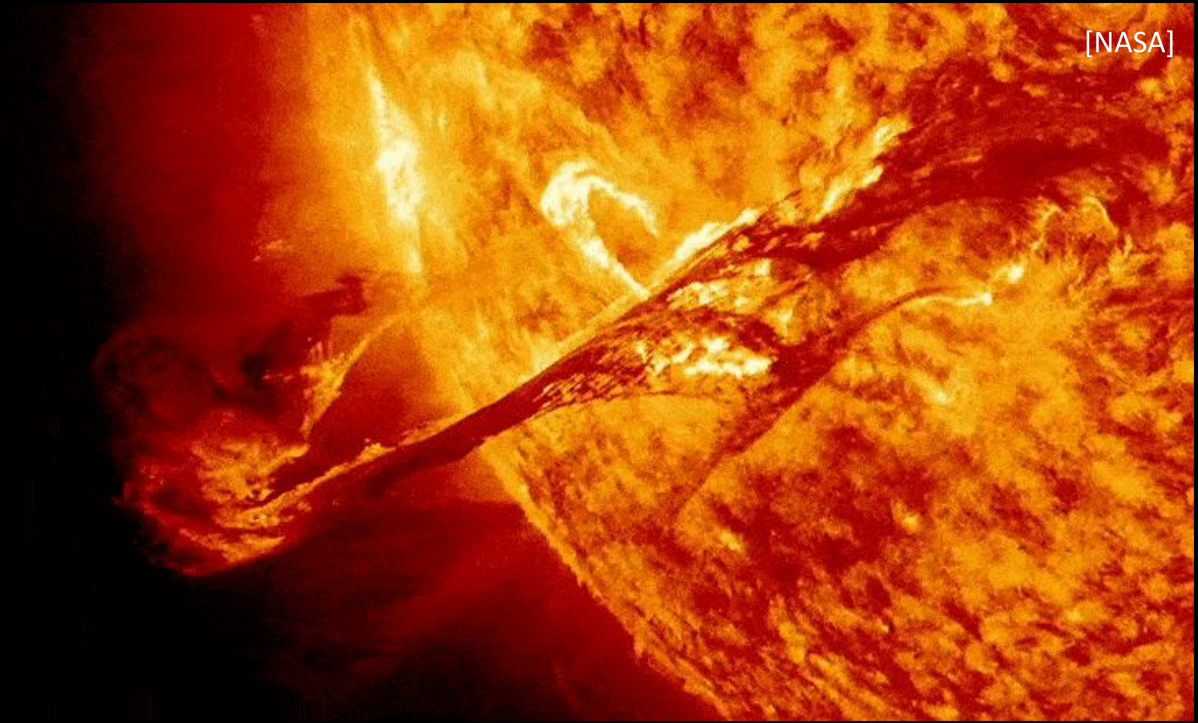
Space weather: solar flares

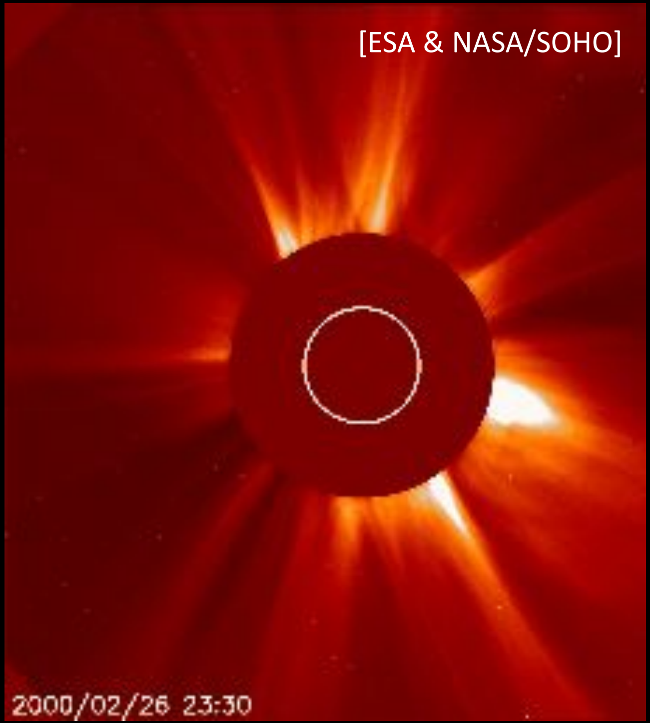




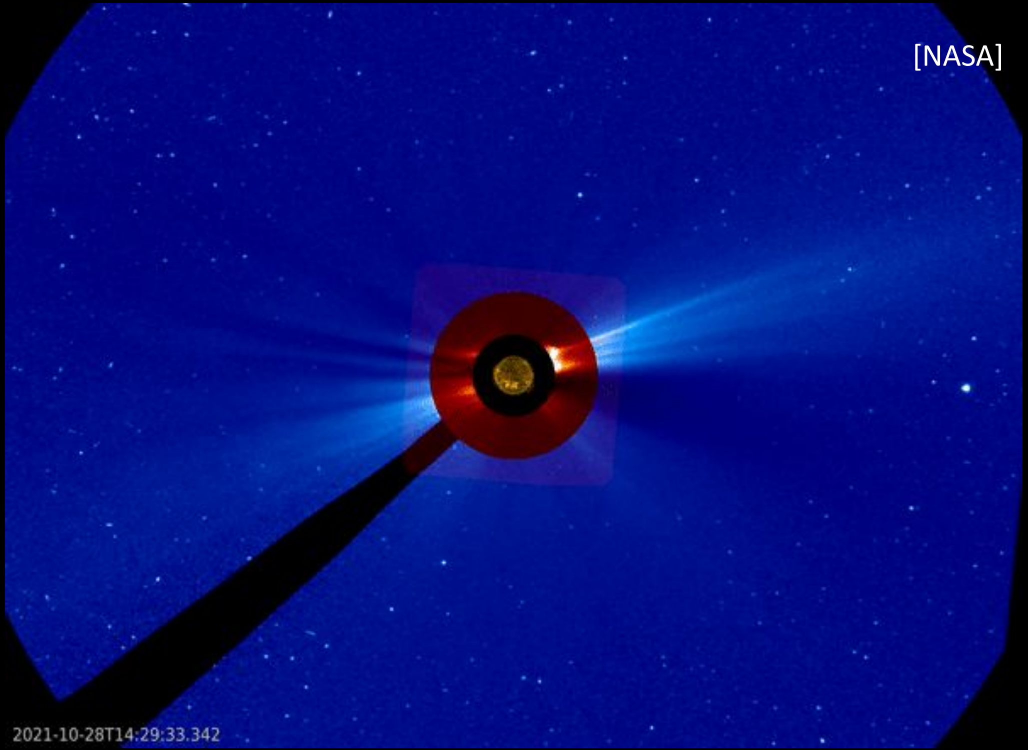
[NASA/SDO]

Space weather: coronal mass ejections

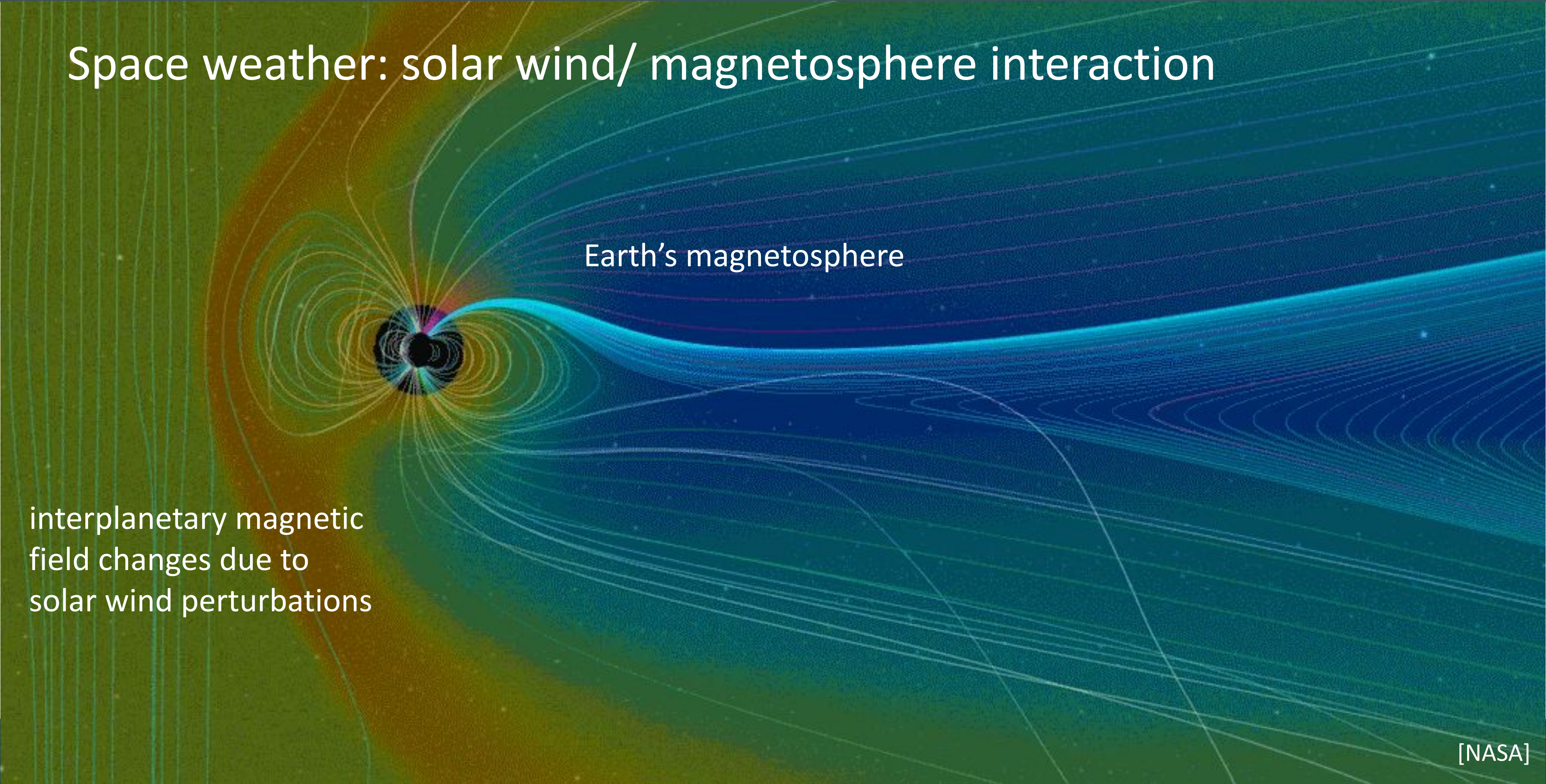




Space weather: particle (radiation) storms

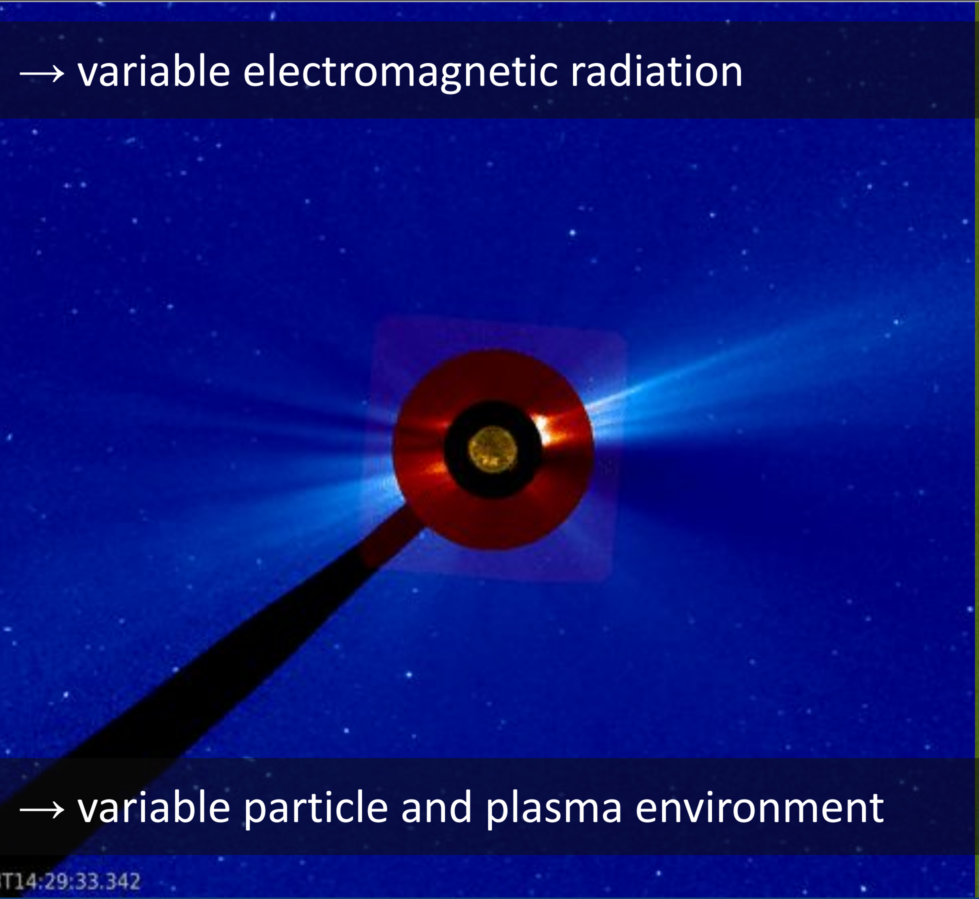


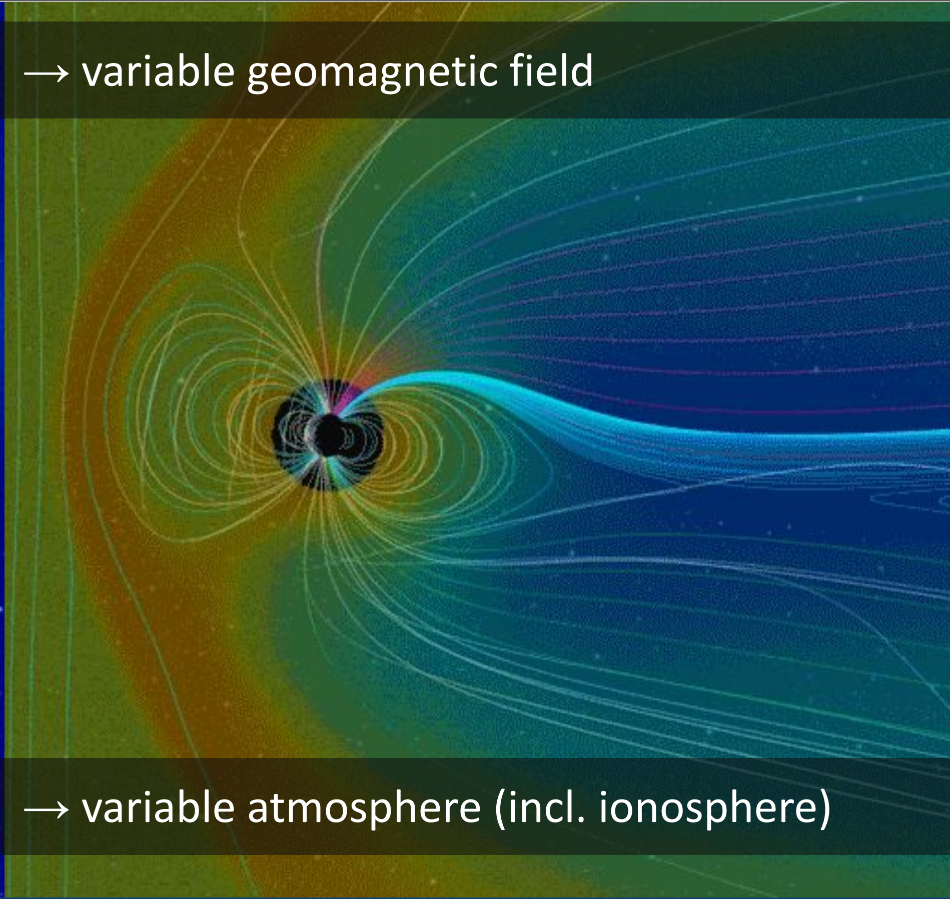
Space weather: solar wind/ magnetosphere interaction



→ variable electromagnetic radiation

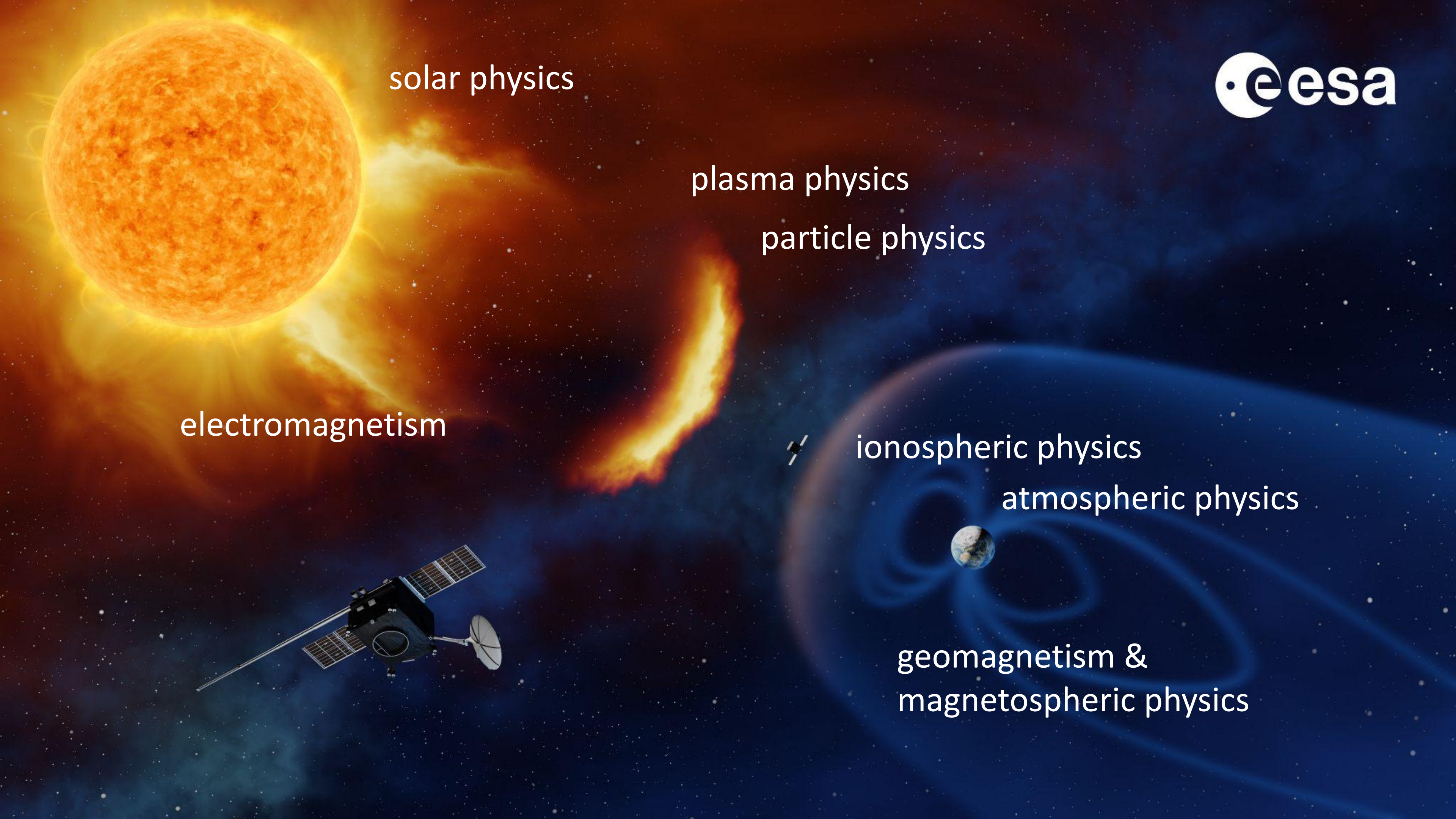
→ variable geomagnetic field

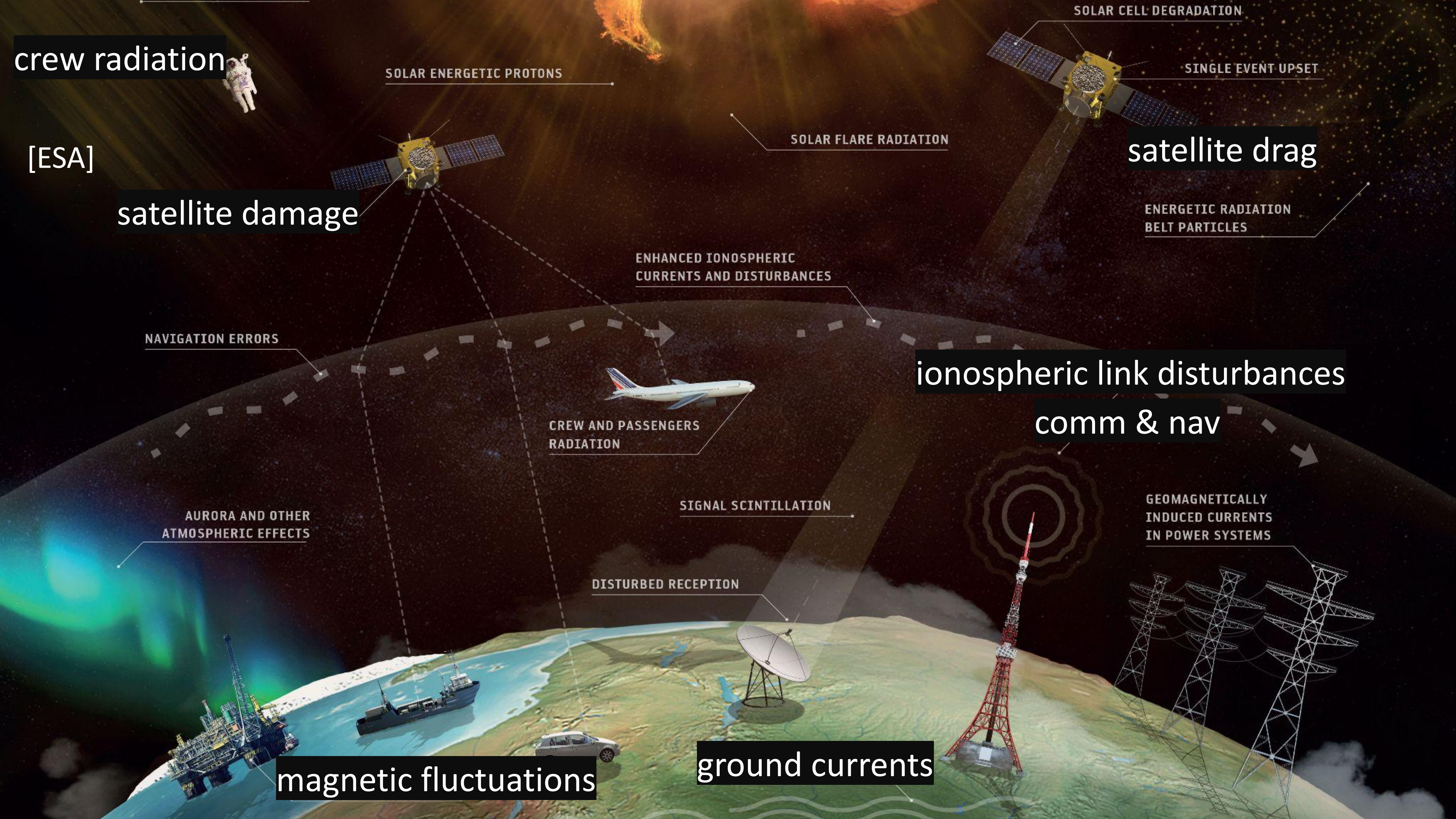




→ variable particle and plasma environment

→ variable atmosphere (incl. ionosphere)


solar physics
plasma physics
particle physics
electromagnetism
ionospheric physics
atmospheric physics
geomagnetism &
magnetospheric physics


crew radiation
[ESA]
satellite damage
SOLAR ENERGETIC PROTONS
SOLAR FLARE RADIATION
SOLAR CELL DEGRADATION
SINGLE EVENT UPSET
satellite drag
ENERGETIC RADIATION
BELT PARTICLES
ENHANCED IONOSPHERIC
CURRENTS AND DISTURBANCES
NAVIGATION ERRORS
ionospheric link disturbances
comm & nav
CREW AND PASSENGERS
RADIATION
SIGNAL SCINTILLATION
AURORA AND OTHER
ATMOSPHERIC EFFECTS
GEOMAGNETICALLY
INDUCED CURRENTS
IN POWER SYSTEMS
DISTURBED RECEPTION
magnetic fluctuations
ground currents

[ESA]

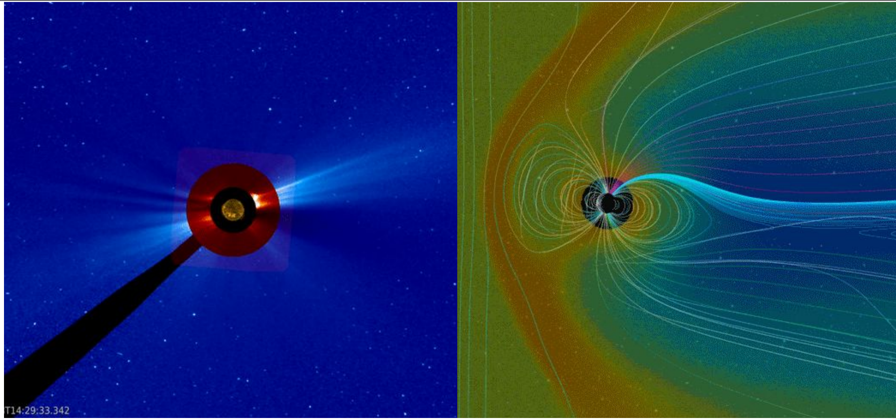
→ interdisciplinary: a lot of different physics & engineering and their coupling

→ many different tools and models

→ sometimes a “detective work” to find a cause

→ **ask & talk to people**

Defence vulnerabilities



- if it:
    - flies in space/ upper atmosphere (or needs assets that do)
    - uses/ detects radio signals
    - communicates through the ionosphere
    - requires magnetic measurements
    - is sensitive to electric currents in the grounds

- **system response often depends on parameters we do not know exactly → still, we have to issue advice & warnings**

SWx vulnerability examples:

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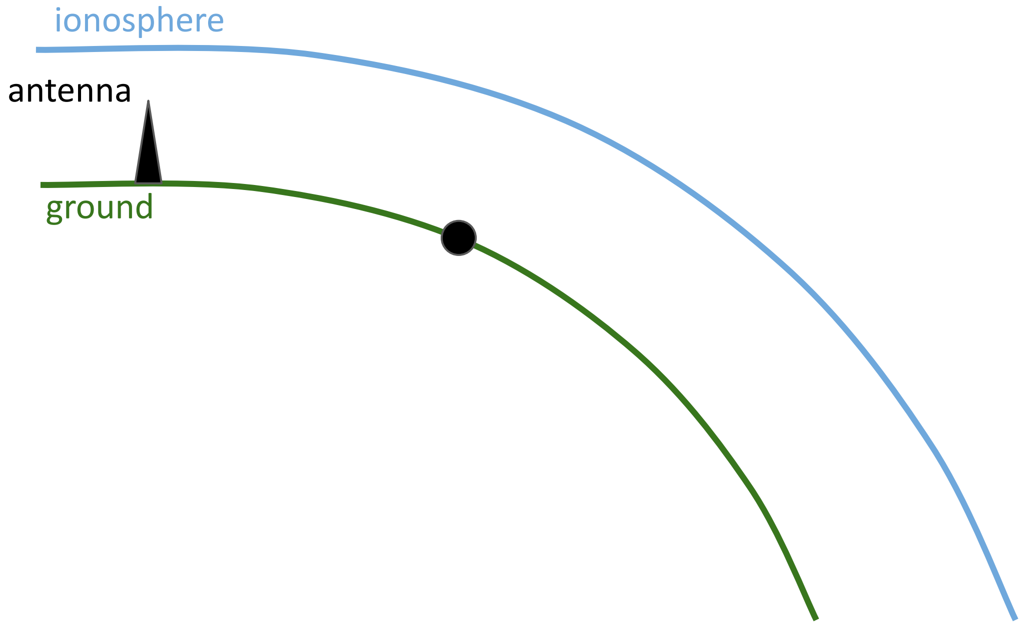
How do we communicate? Why is the ionosphere important?



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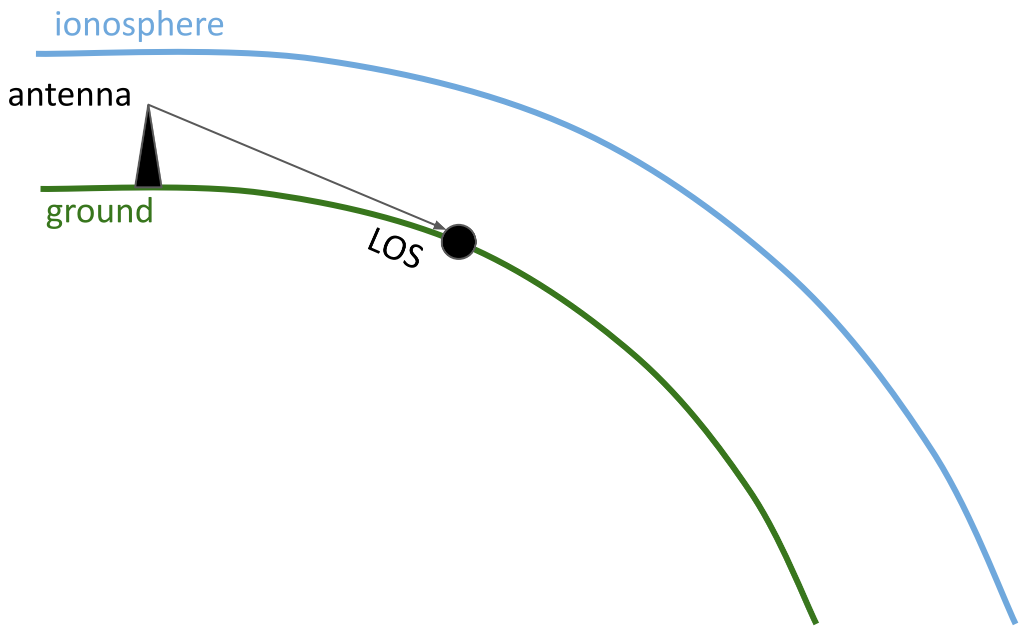

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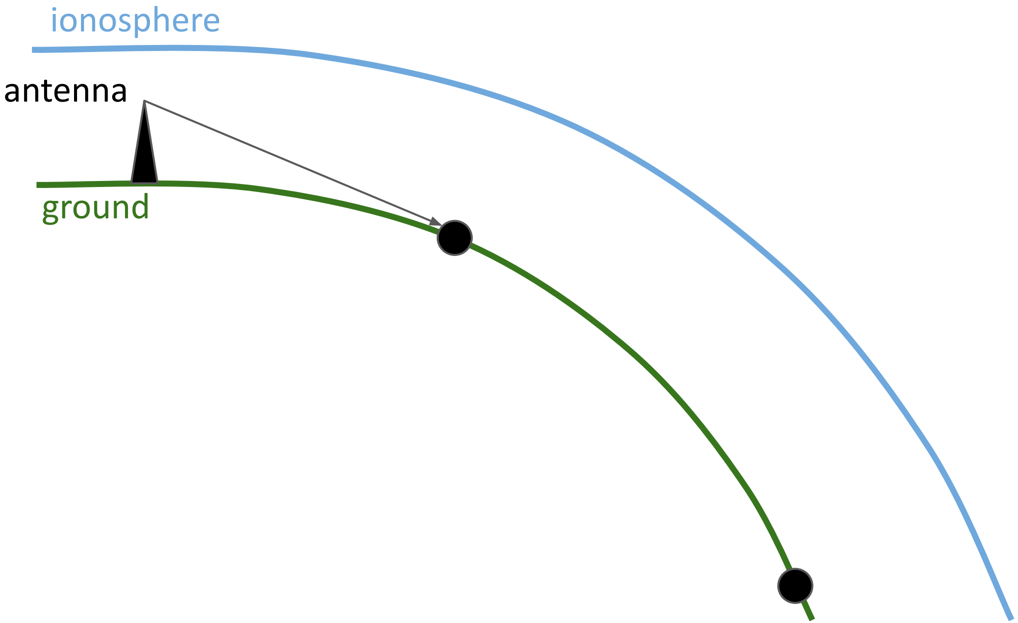

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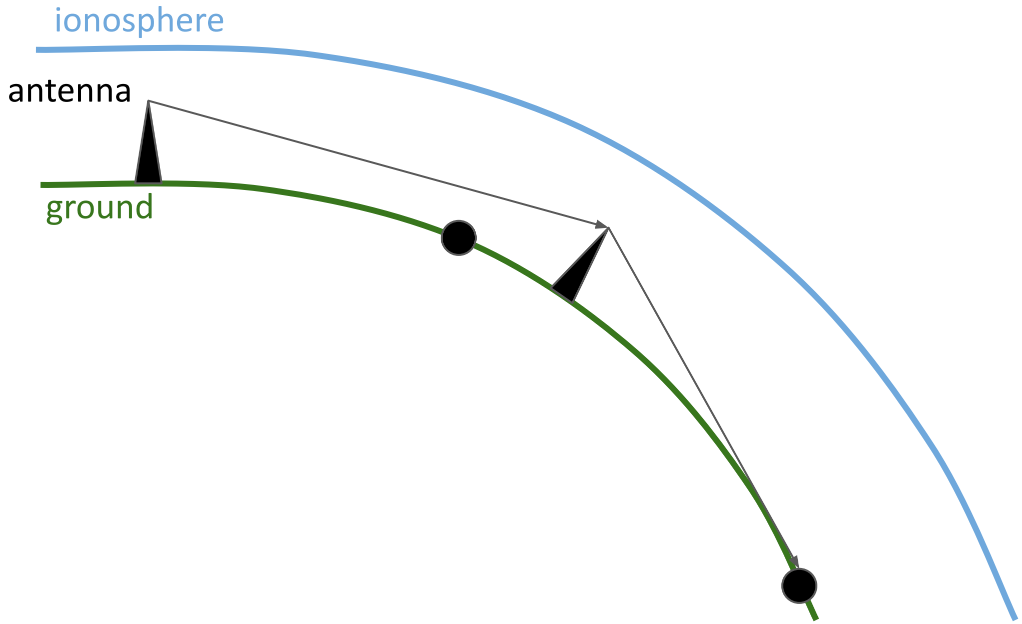

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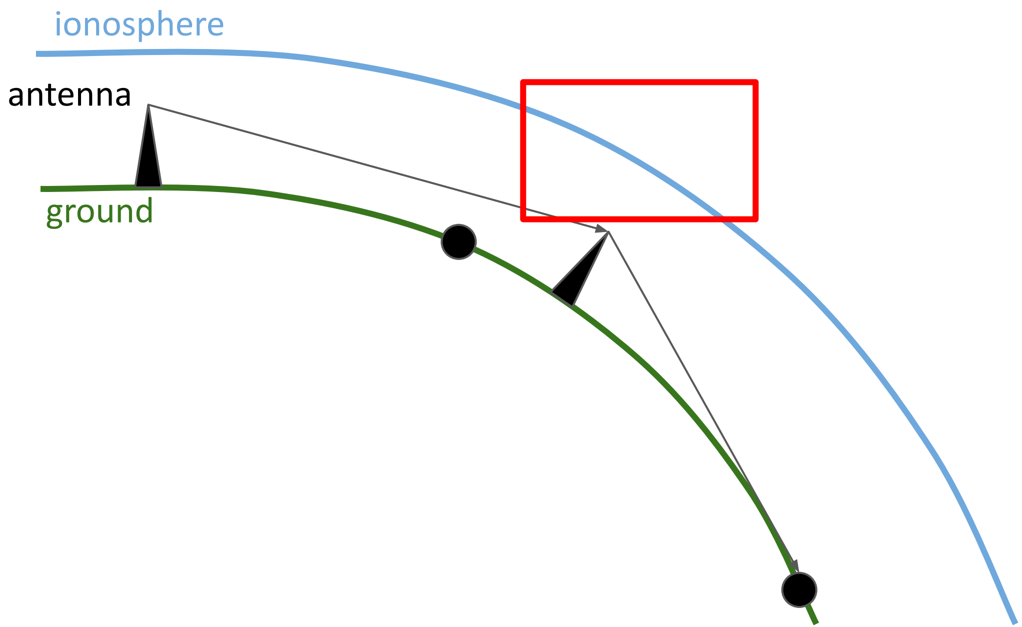

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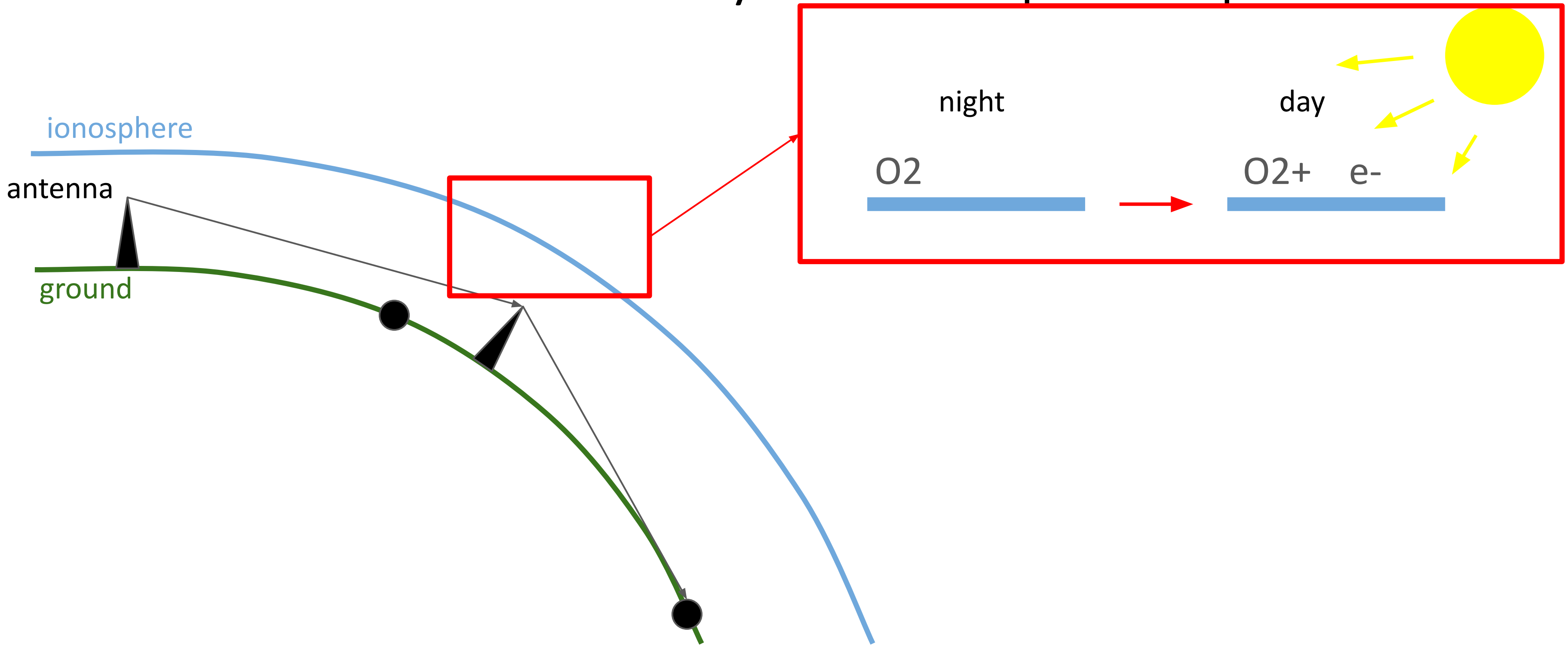

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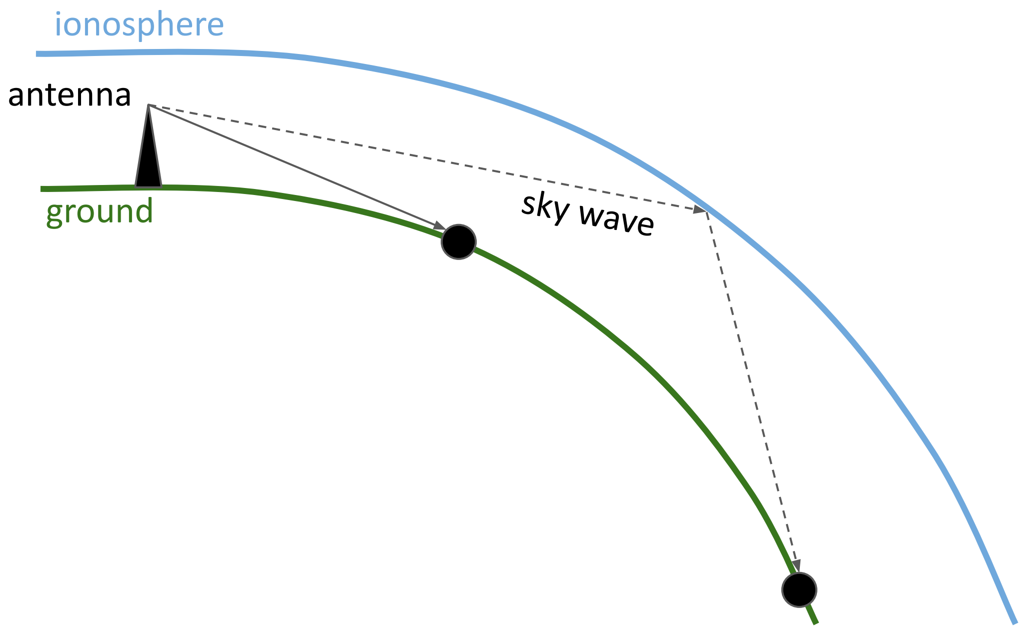

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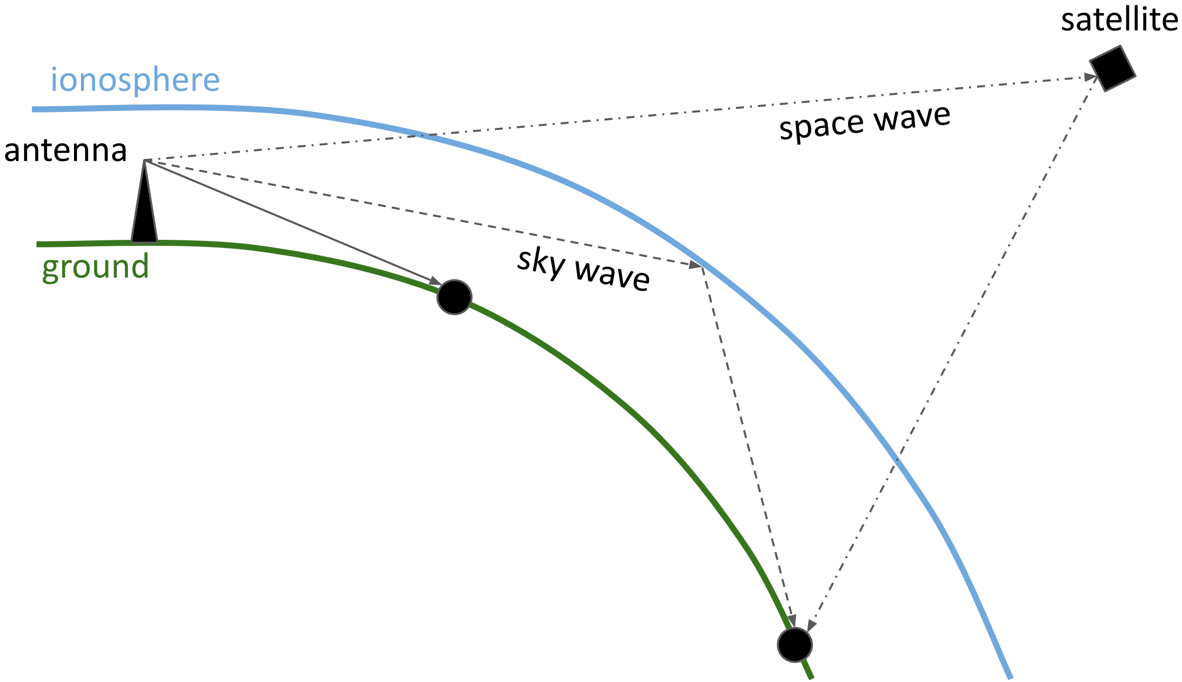

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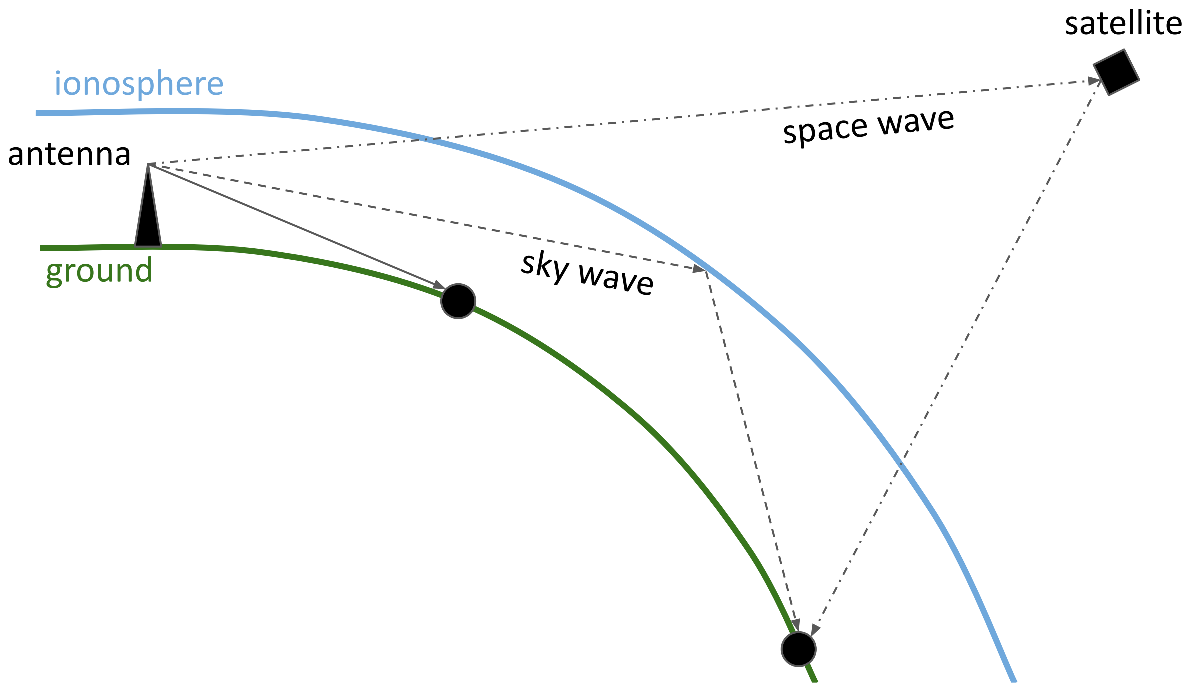

- HF more and more important due to anti-sat weapons and satcom jamming (Ukr)

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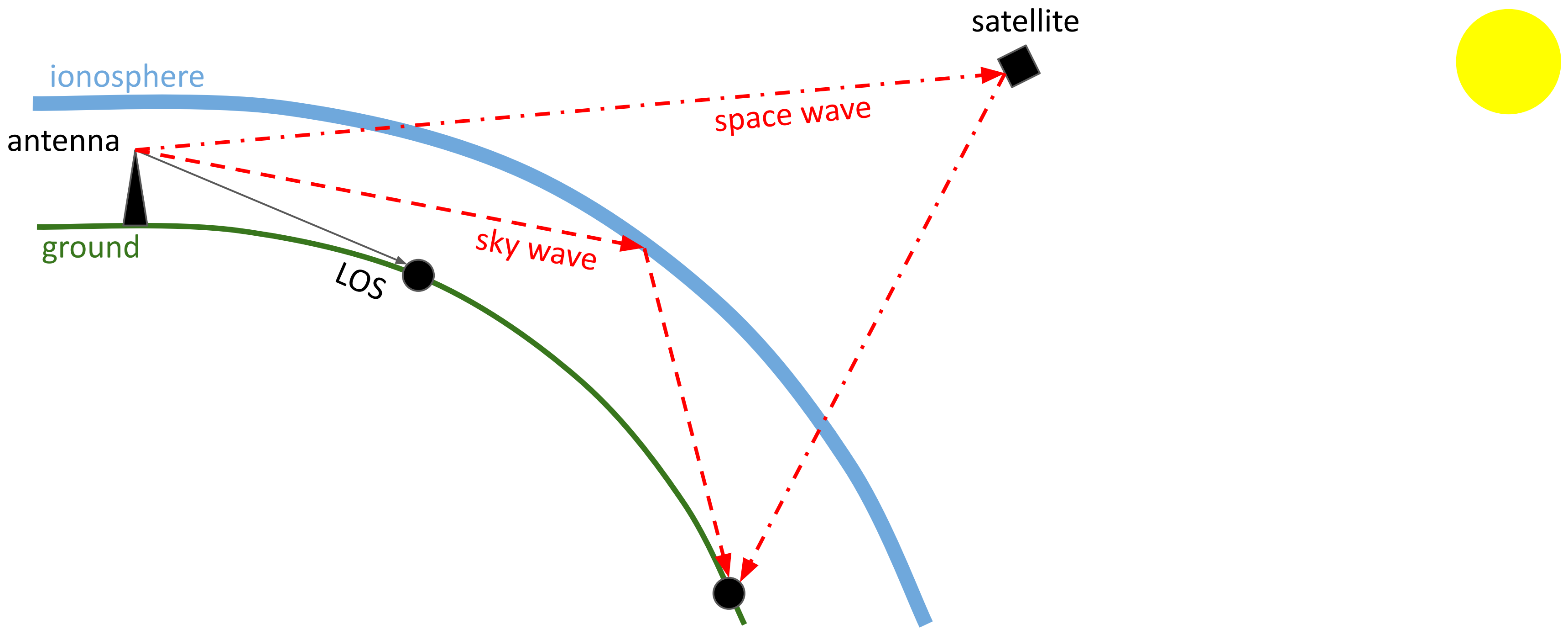
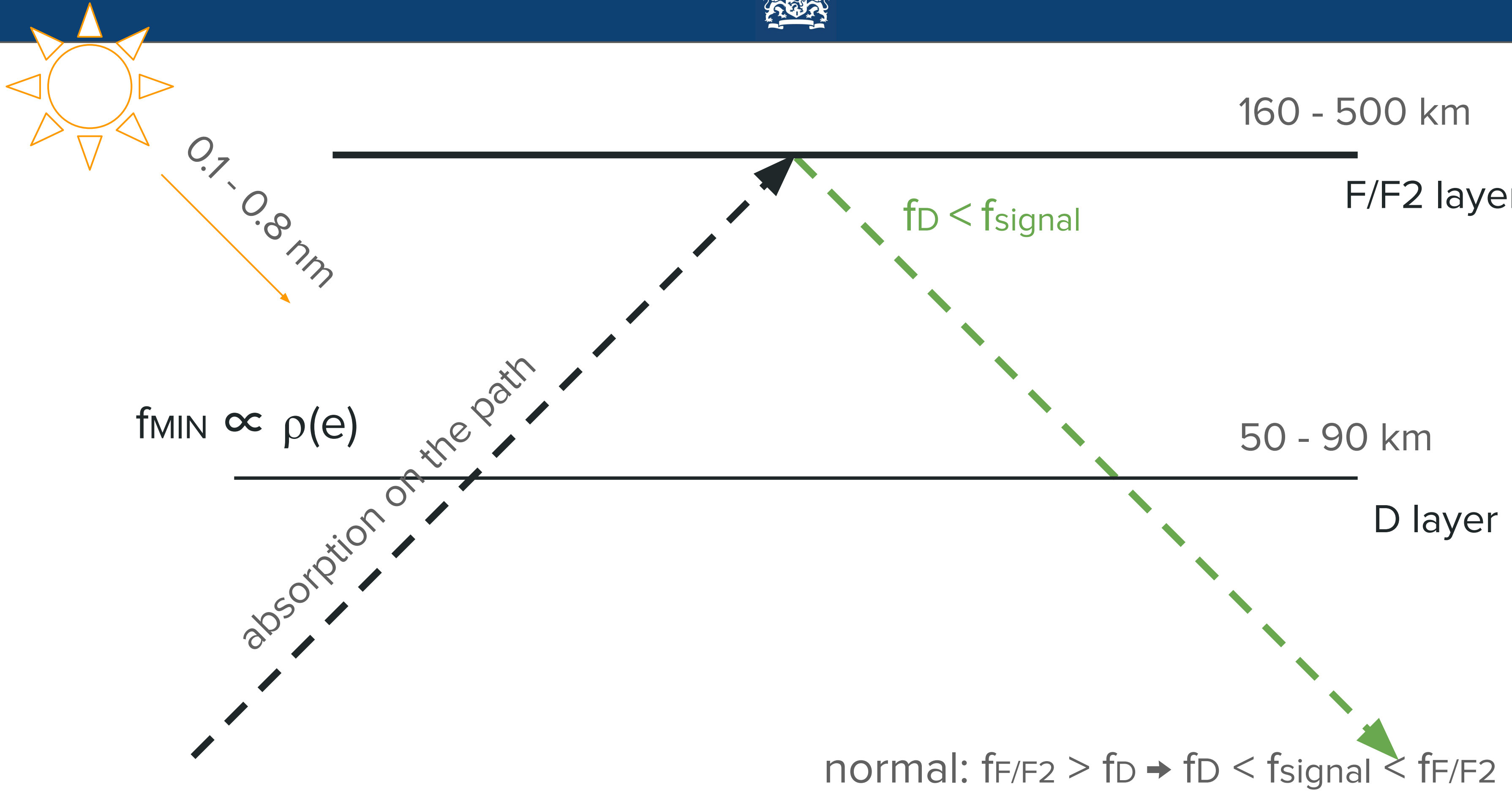
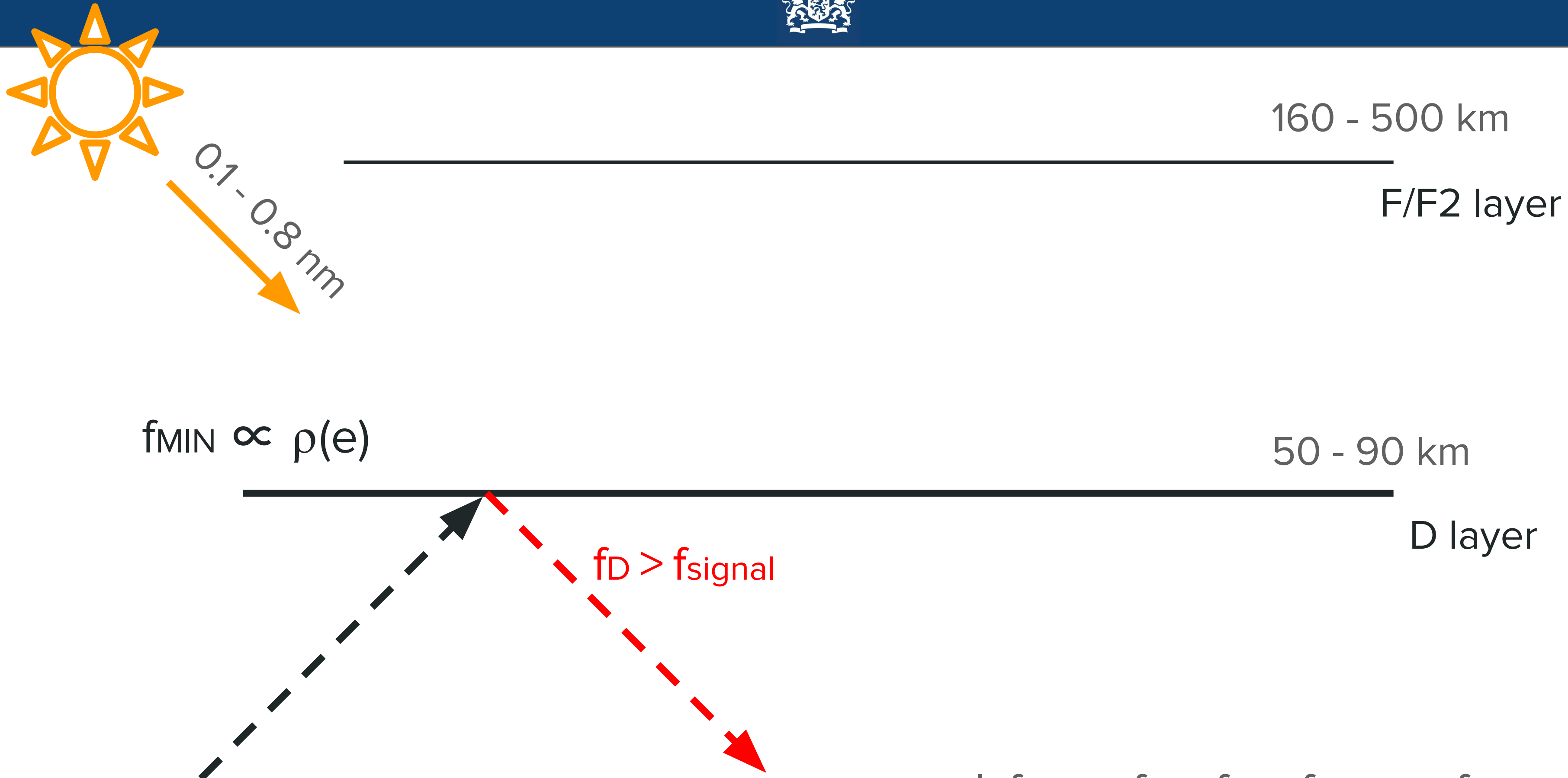




160 - 500 km
F/F2 layer
$f_D < f_{signal}$
0.1 - 0.8 nm
$f_{MIN} \propto \rho(e)$
absorption on the path
50 - 90 km
D layer
normal: $f_{F/F2} > f_D \rightarrow f_D < f_{signal} < f_{F/F2}$



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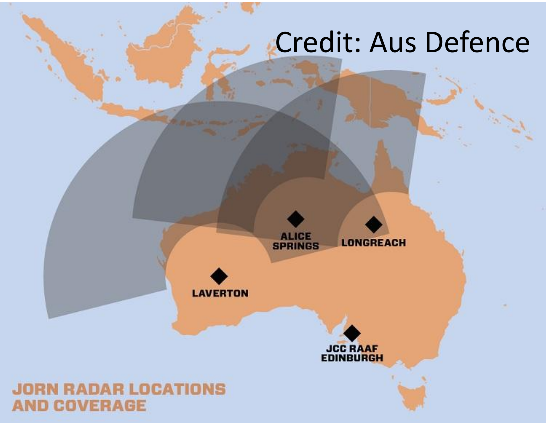
Credit: Harris



Credit: Aus Defence

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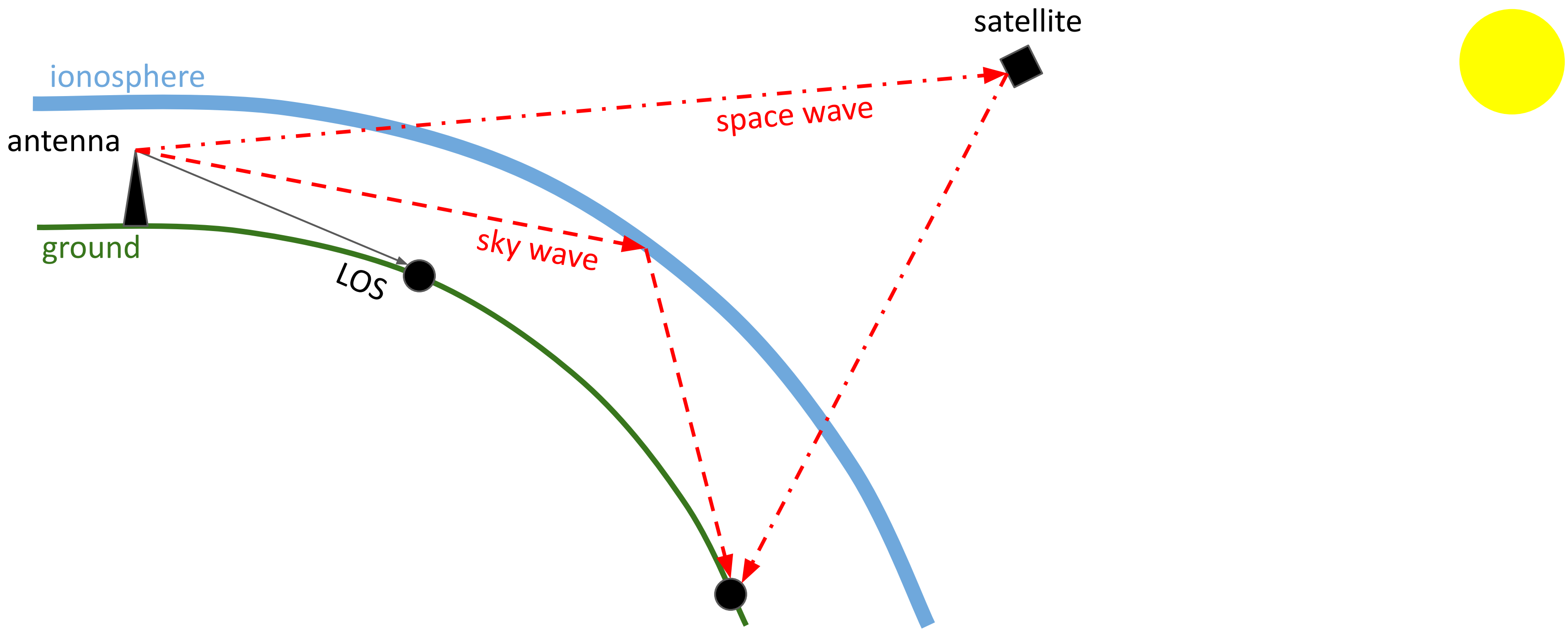

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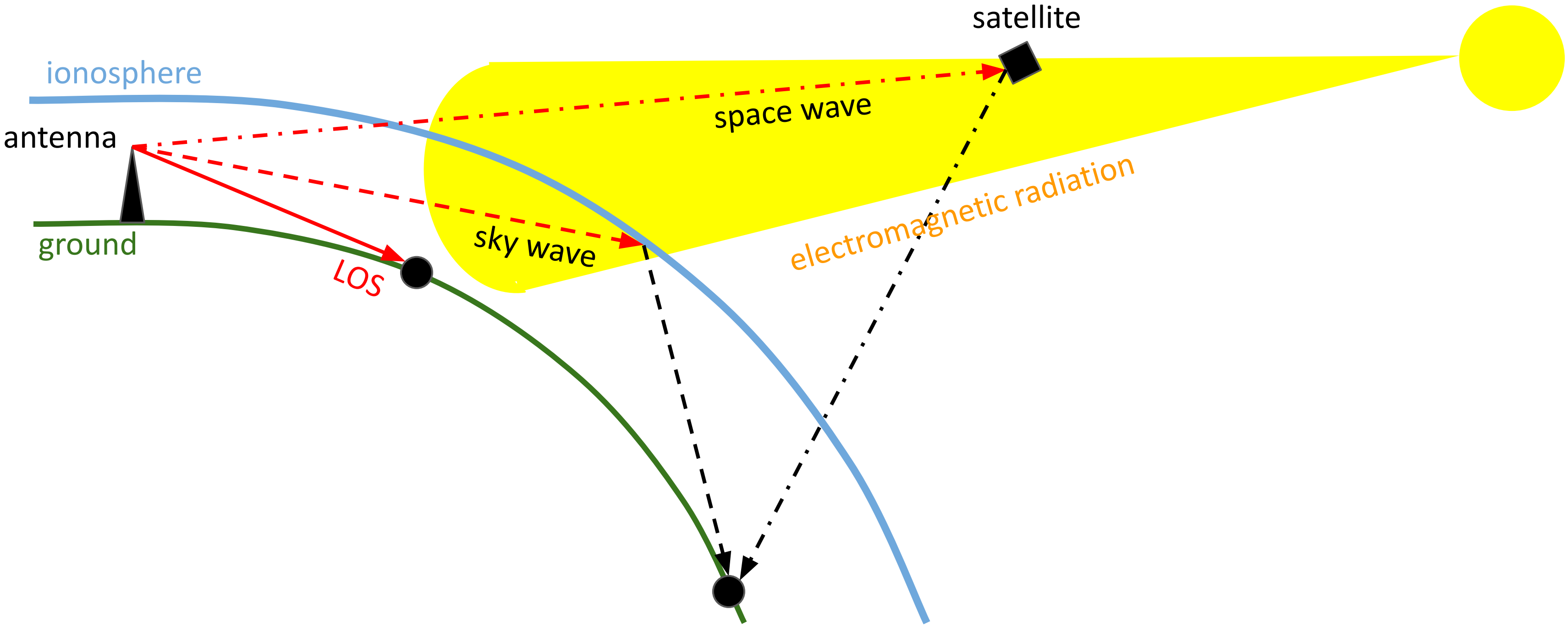

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Credit: Naval Technology

Credit: T. Baba

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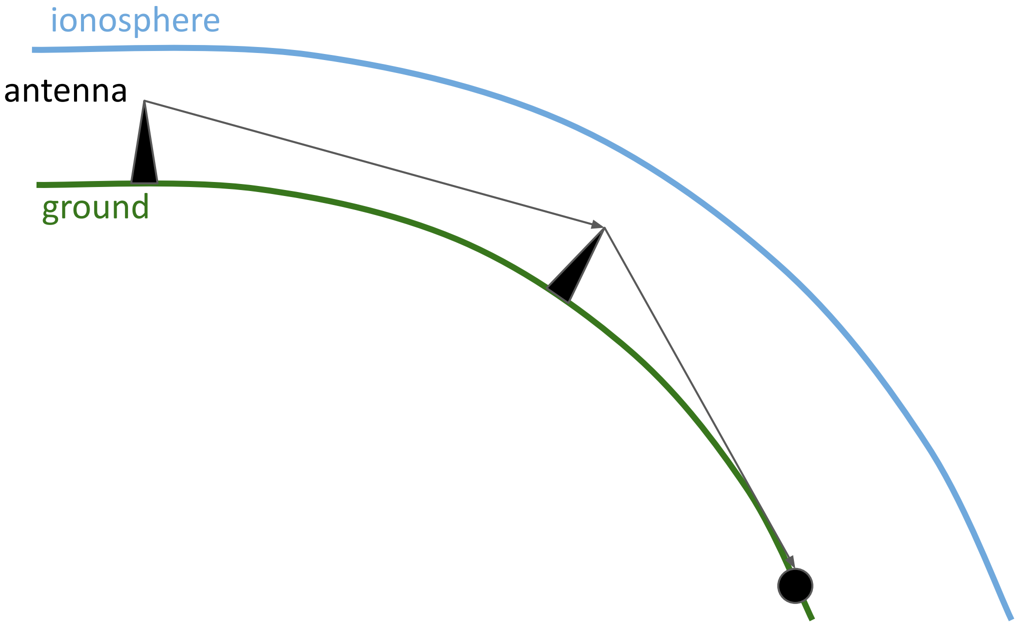

32

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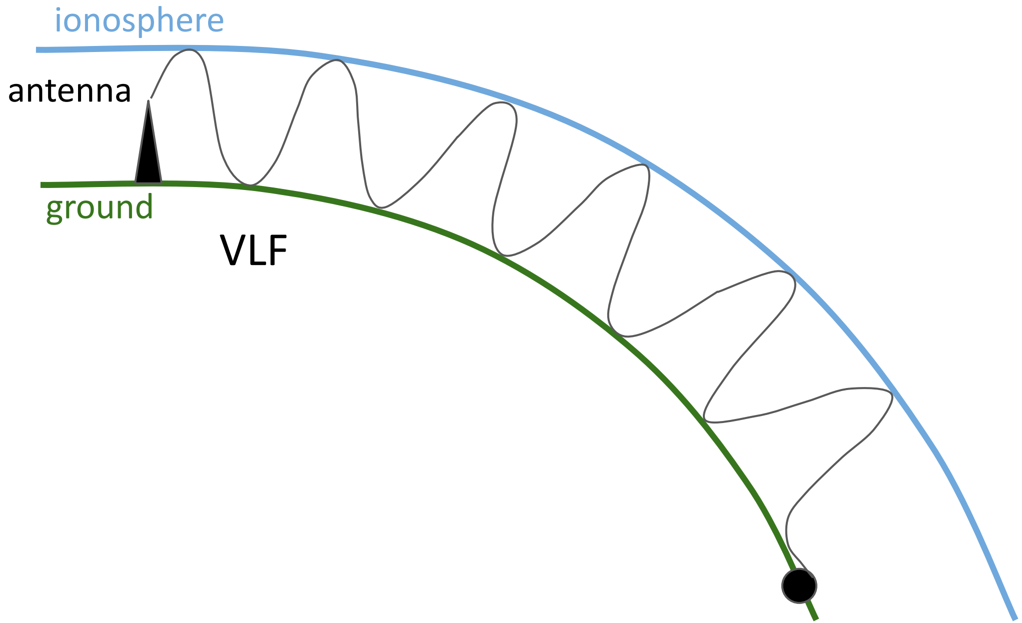

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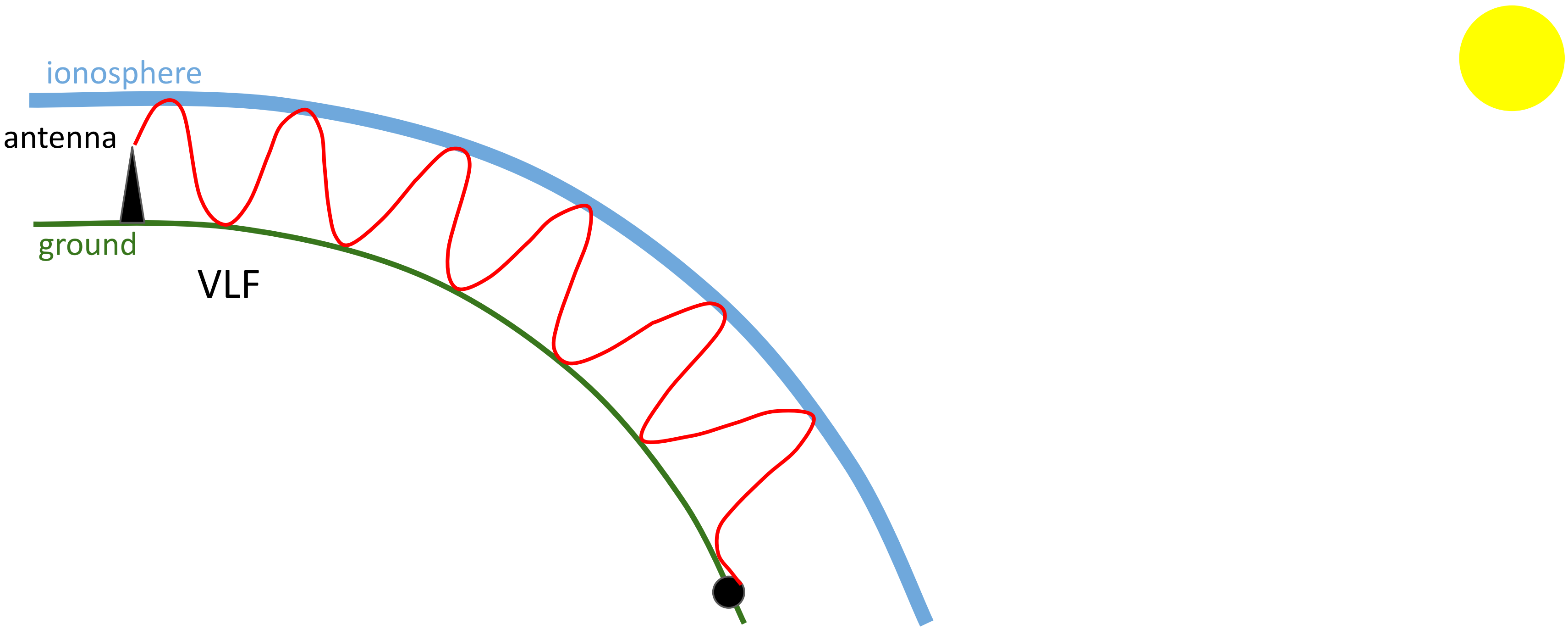

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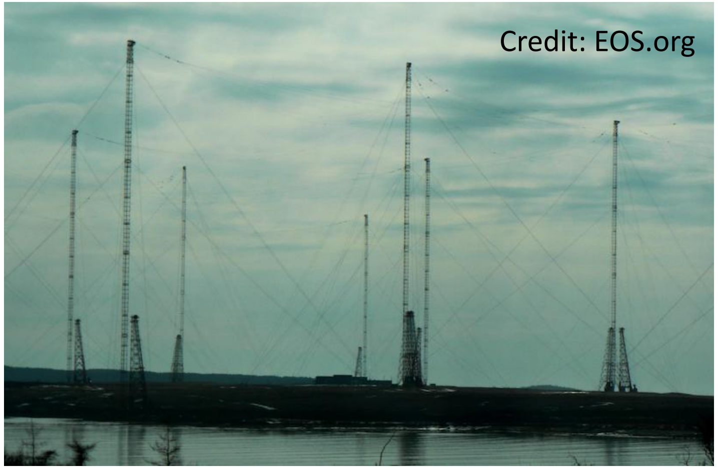

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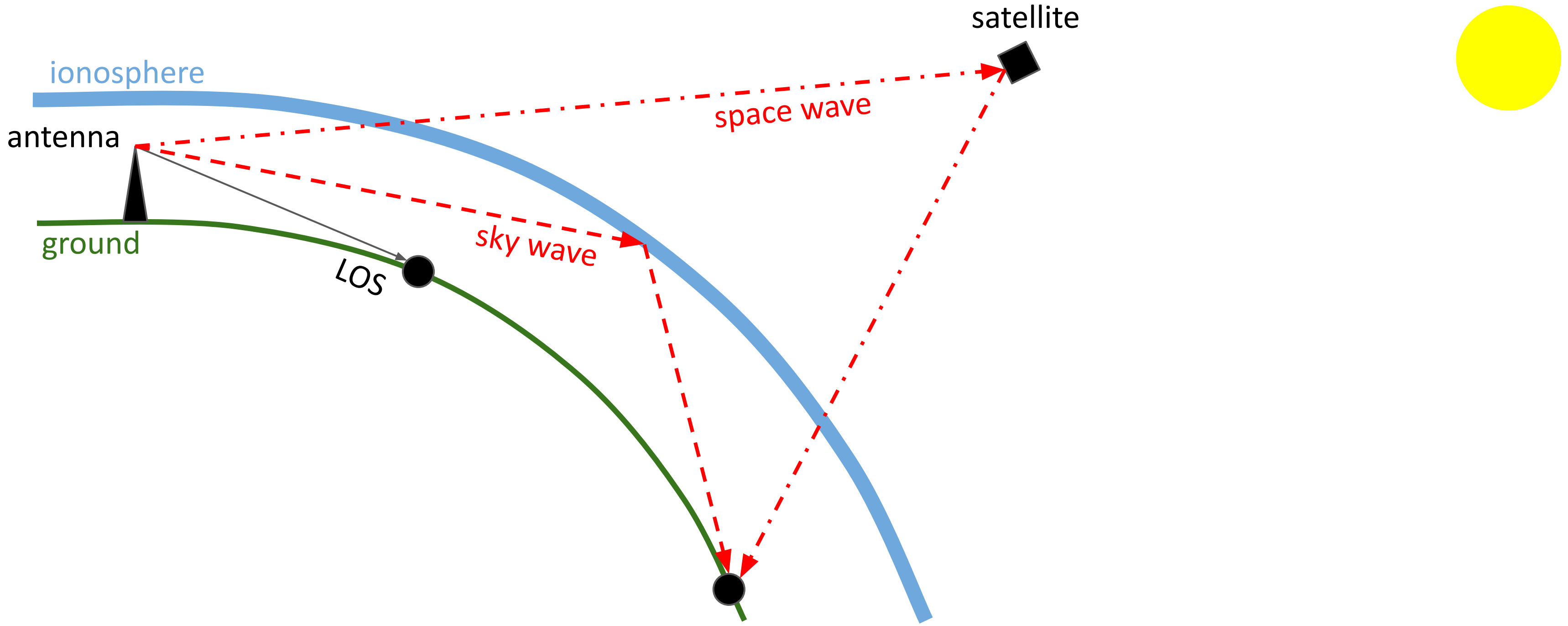

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Credit: AeroVironment

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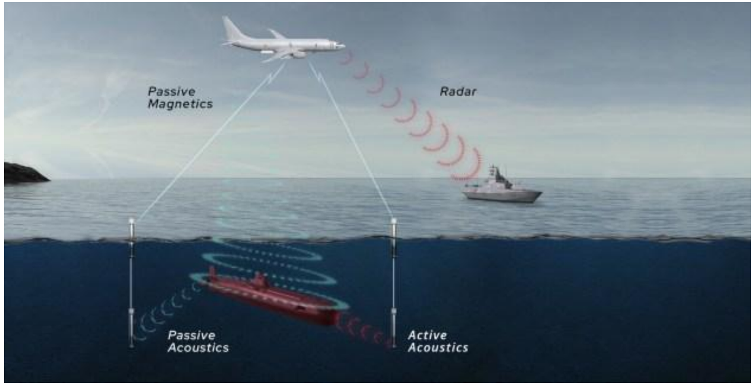
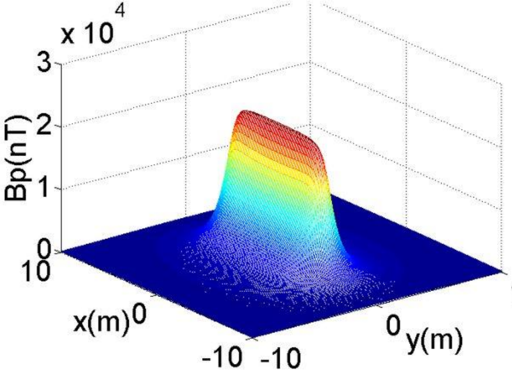


Credit: Australiandefence.com

Credit: Guo et al. 2012



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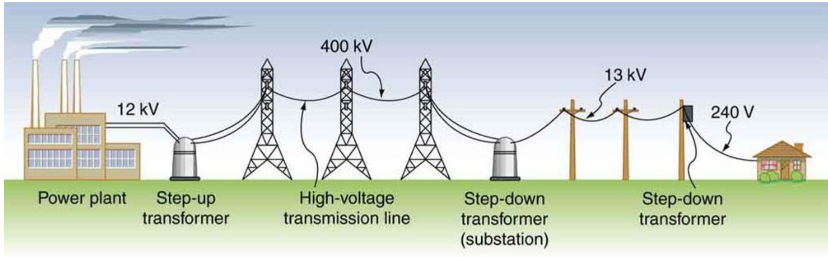

Credit: Lumen

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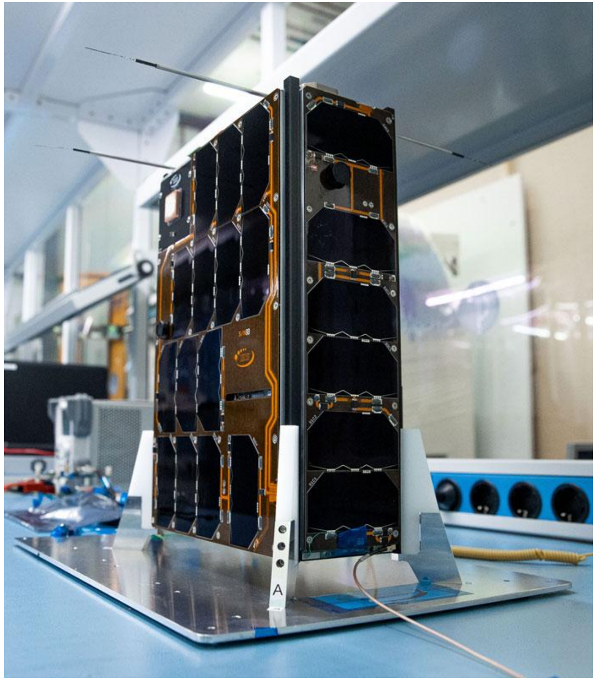
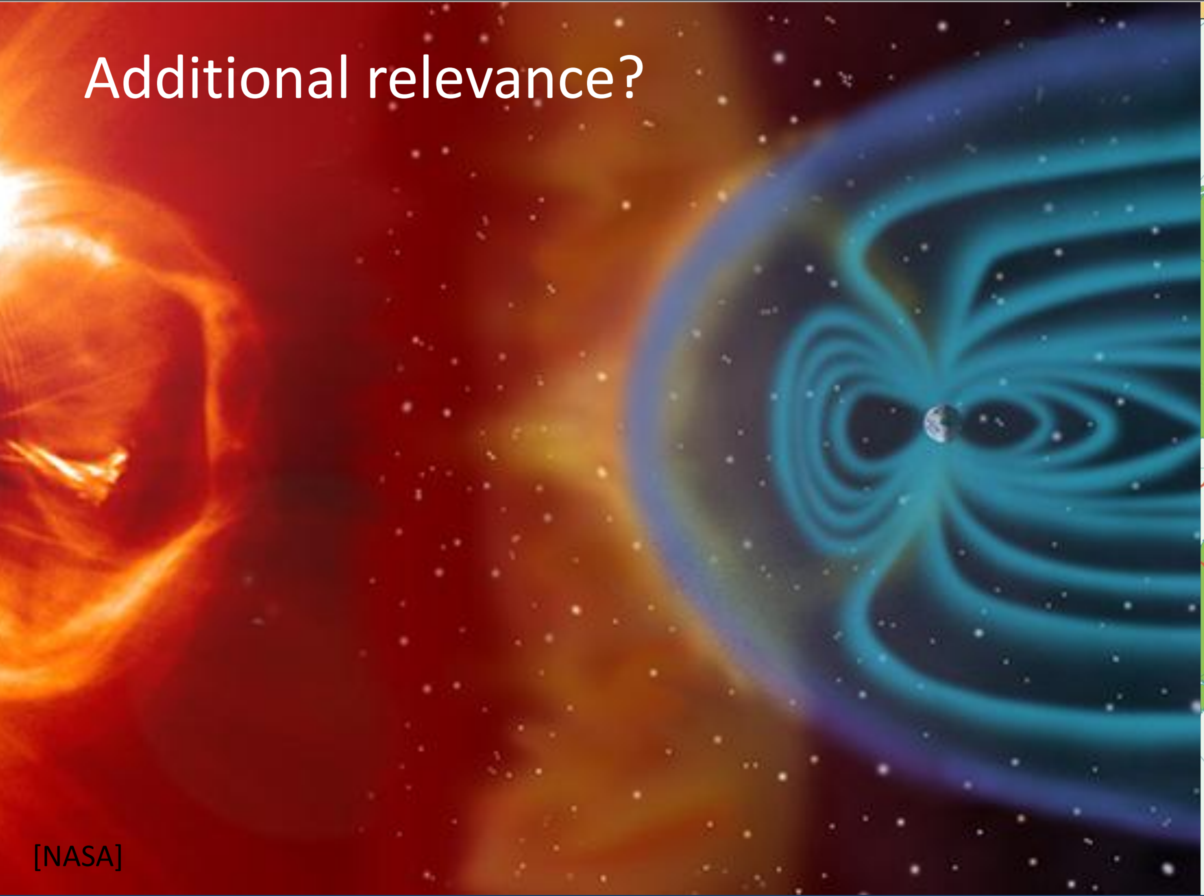
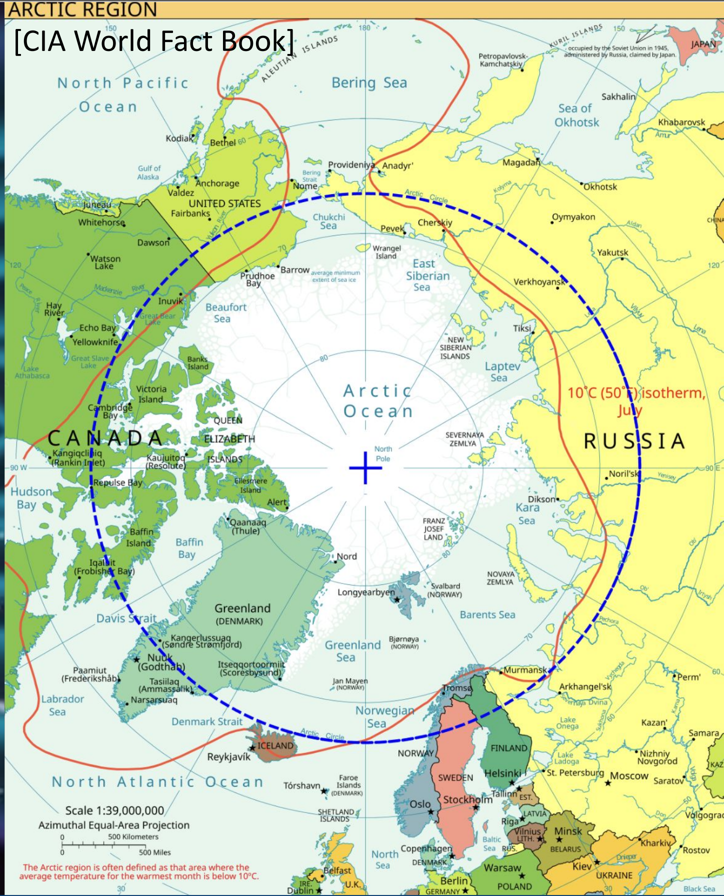
Credit: ISISpace



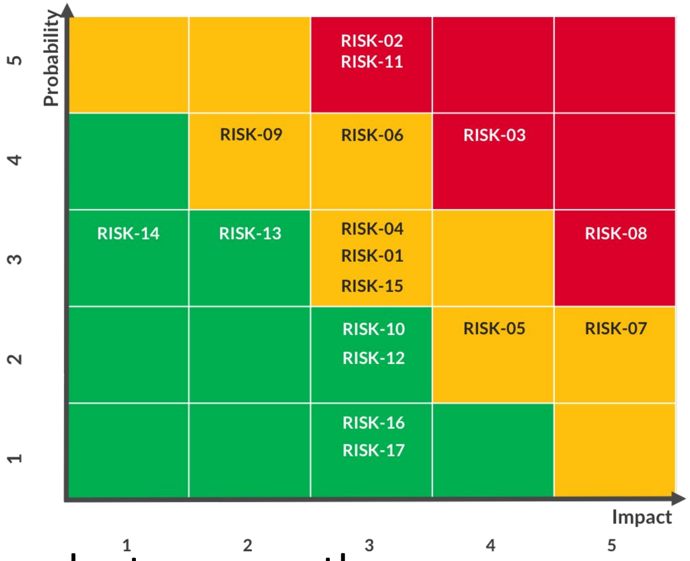
Additional relevance?



[NASA]



Space weather (SW) effects risks



- when evaluating SW risks, looking at the probability alone is often not enough:

  risk = probability x cost

- cost may be political, military, societal, financial, etc.

- the resulting risks are organisation- and platform-dependent, e.g., on the procedures in place, the protocols and the system diversity/ redundancy

  → **up to the user to decide!**

Reception VHF advertisements in Gilze-Rijen

- ~ 40 MHz advertisement originated from Israel, how to stop this?
- VHF line-of-sight (LOS) only: ionosphere normally only reflects up to ~ 30 MHz

- What causes ionospheric disturbances?
  - solar flares → none strong detected that day
  - proton storms → not in polar regions + no proton storms detected that day
  - geomagnetic storms → none strong that day/ days prior

- check ionospheric total electron content maps → no extraordinary patterns
- check ionogram data of nearby stations → strong E-layer normally not there

  → **reception and noise due to a sporadic E-layer**

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- chec
- chec

→ not a problem during an exercise

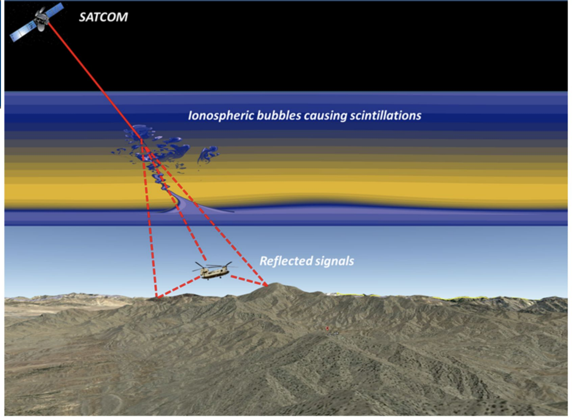
→ but what would happen during an actual mission?

2002 The Battle of Takur Ghar (Afghanistan)

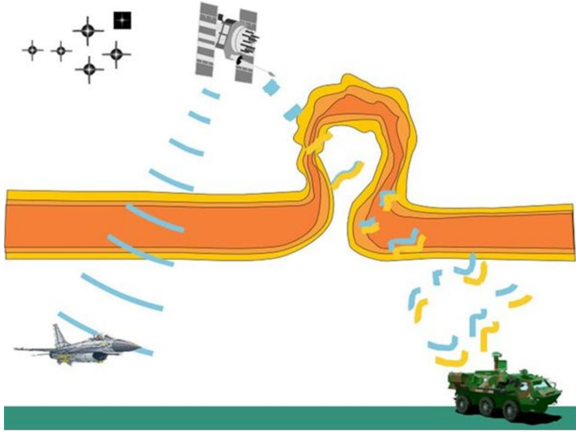
- plasma bubbles post-midnight might occur due to increased geomagnetic activity of Kp > 3: the battle of Takur Ghar: Kp = 4, 0300 LT March 4, 2002

- during the battle, Chinook helicopters from the QRF were called to help Navy SEAL units, landing at Takur Ghar (Afghanistan)

- in the meantime, the area became "hot", but the helicopters never received the repeated warnings avoid the area → the Chinook crashed and seven people died



Sketch prepared by ROB/GNSS (Dr Nicolas Bergeot) with NICT/AERI – Dr Yokoyama's model as base http://aer.nict.go.jp/en/people/spe_yokoyama.html



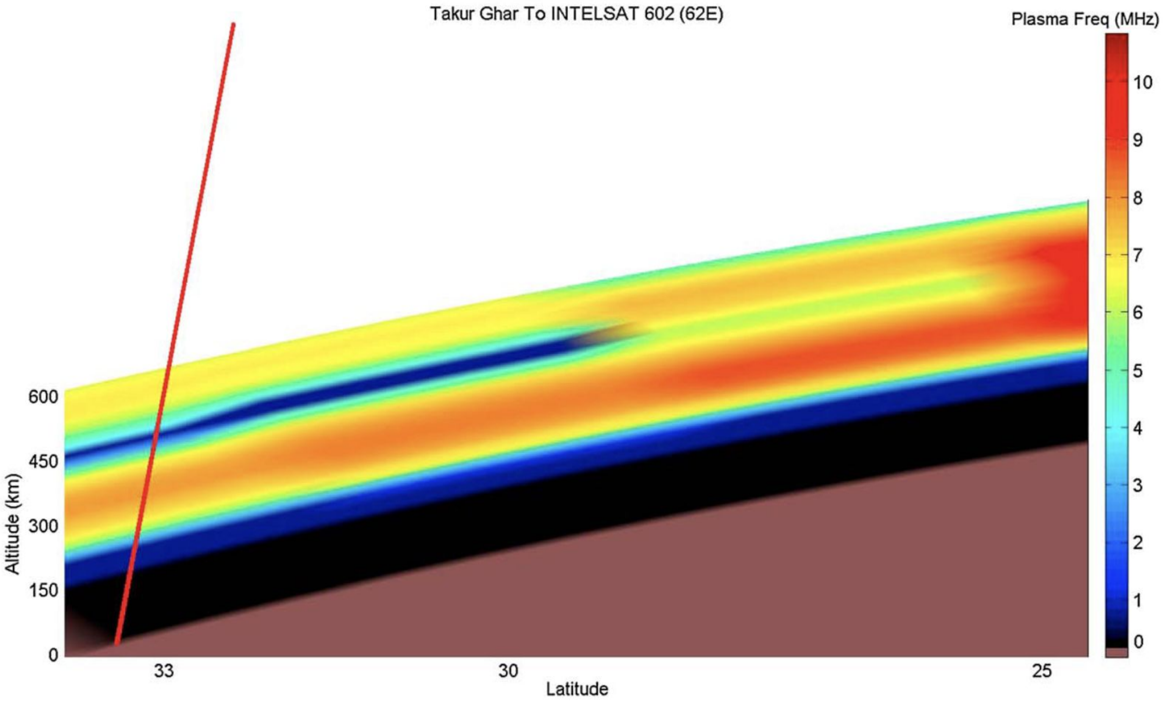
Credit: U.S. Air Force Research Laboratory (AFRL)
https://www.nasa.gov/mission_pages/cindi/five-years.html

2002 The Battle of Takur Ghar (Afghanistan)

Kelly et al. 2014

- GUVI UV data - electron density reconstruction show clear depletion regions consistent with plasma bubble (Kelly et al. 2014)

  → it is likely that plasma bubbles was what caused the loss of lives and the failure of the operation



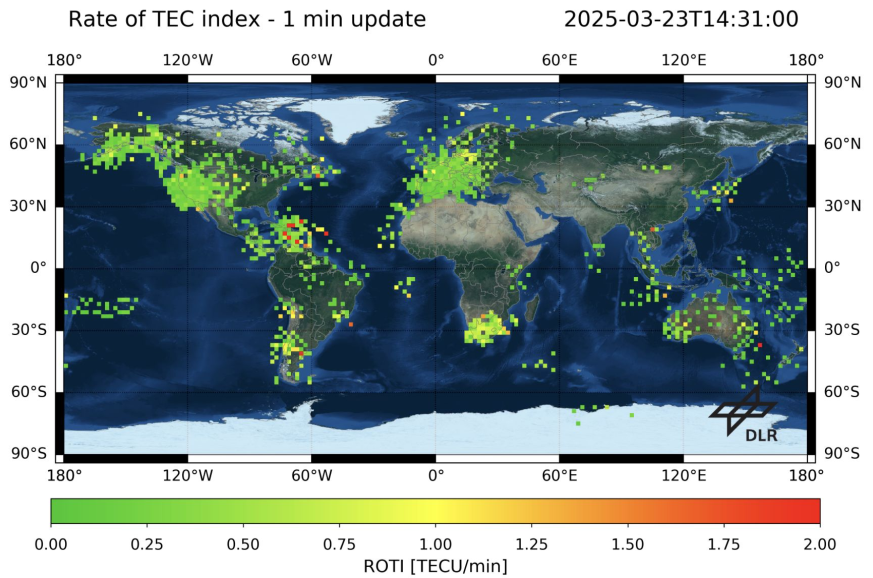
Examples of SWx vulnerabilities

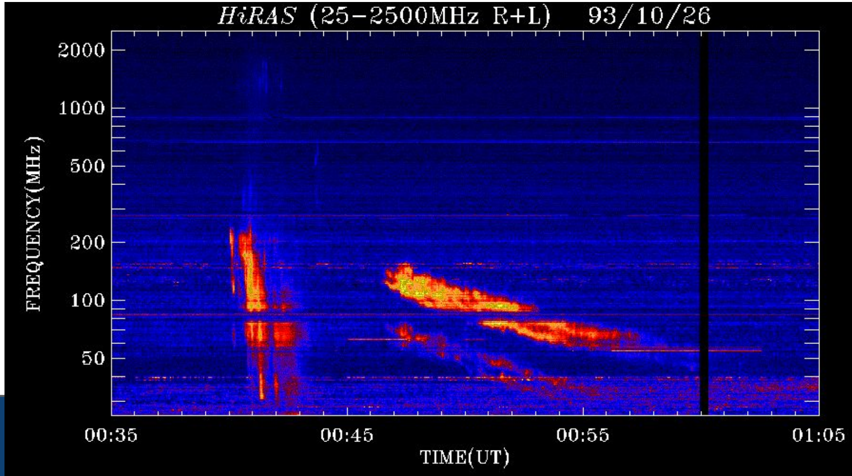
- HF-radio system for long-distance comms:

  … but needs time-synchronisation from GPS/ GNSS

- UHF radio with several channels on a drone

  … with all the channels within 20 MHz from each other





SW issues: footprints?

- “technical failures” that later disappear
- too much extra “noise”
- some are resolved within minutes
- some last for hours/ days

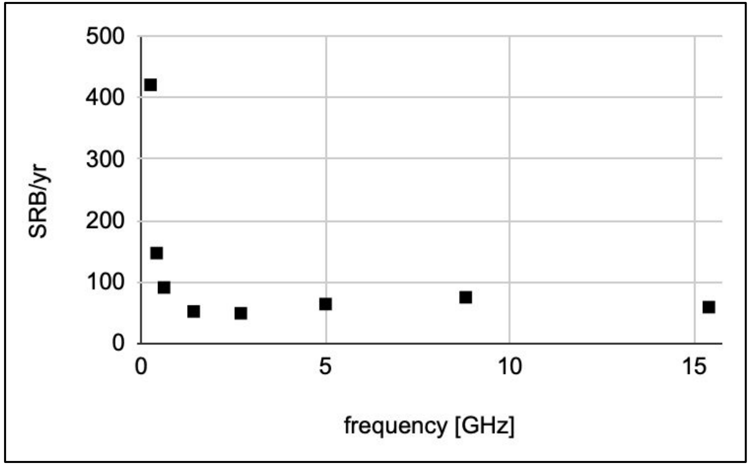
- essential to know what these look like in different systems but:
  - operator awareness largely lacking
  - insufficient applied SWx research

Credits: Lockheed Martin

→ **if you can, engage the operators to get back to you if something happens**

Questions to be asked (and answered)

- is this really a problem?
  - how often does this happen?
  - which systems are affected and how much?
  - what are the consequences in operations?



own work based on Giersch et al. 2017

- if so, is there something we can do about it?
  - operational settings adjustment, e.g., frequencies?
  - increasing redundancy, or better design of existing systems?
  - fast-tracking/ delaying operations? Improving awareness?

→ **ongoing efforts to identify the most vulnerable systems & their responses**

Strategic SWx challenges

Credits: NOAA

- US dependencies in our infrastructures:
  - interplanetary magnetic field data at L1
  - solar magnetogram measurements
  - (near) real-time X-ray & EUV measurements
  - modelling of D-layer ionospheric absorption
  - atmospheric models (what does ESA use?) …

- now free & open access, will data still be shared within NATO? What if NOAA/ NASA become privatised? How many services can be kept up with > 10 - 15% staff fired?

→ **ongoing efforts to identify weaknesses and remove these where possible**

Thank you for your attention (and good luck!)

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Operational SWx challenges

- a lot of academic funding on this:
    - academics not rewarded for high technological readiness products
    - academics do not know what Defensie needs

→ the models in use are mostly from US and long ago (and insufficient)

- important to improve operator-forecaster-researcher communication
    - for better understanding of the scope of the effects & risks
    - for better models to forecast these effects

→ **ongoing efforts to promote collaboration & communication with scientists**