International Space Weather Summer Camp 2022: How to turn measurements into an analytical model – at the example of VLF data

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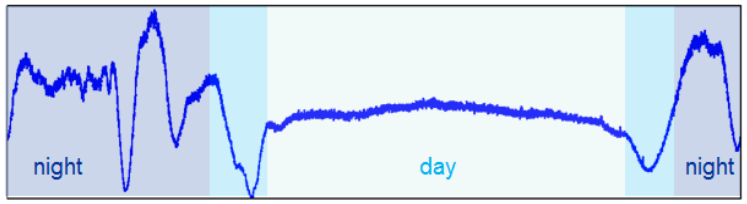
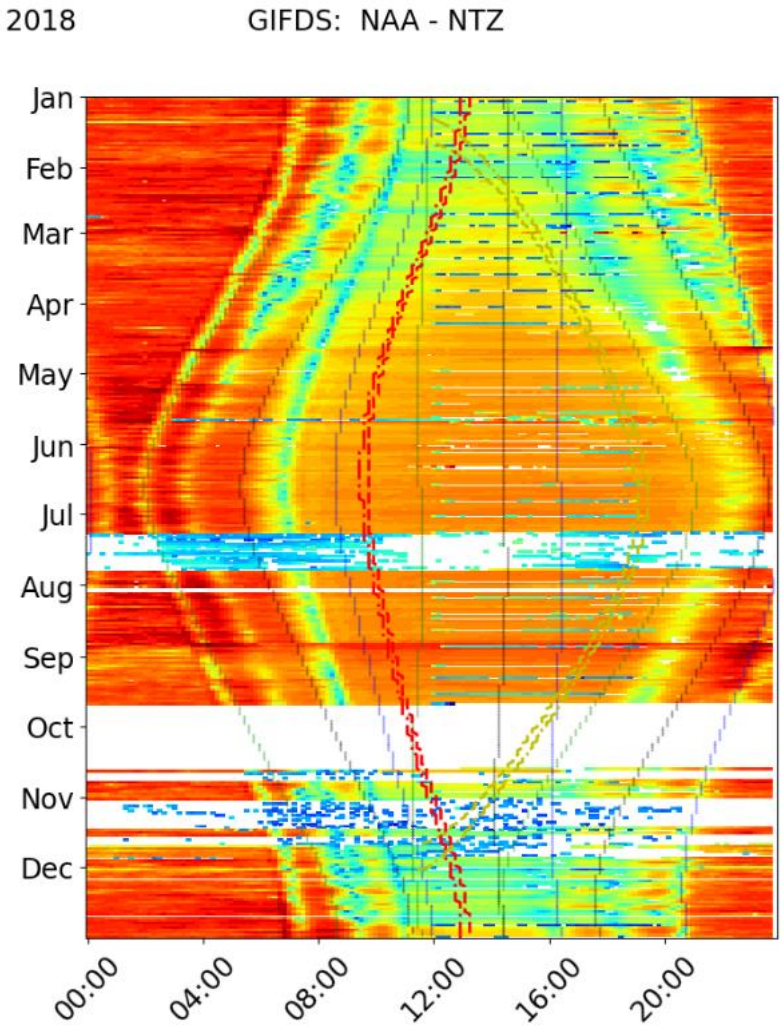
Daily variation

Measurements

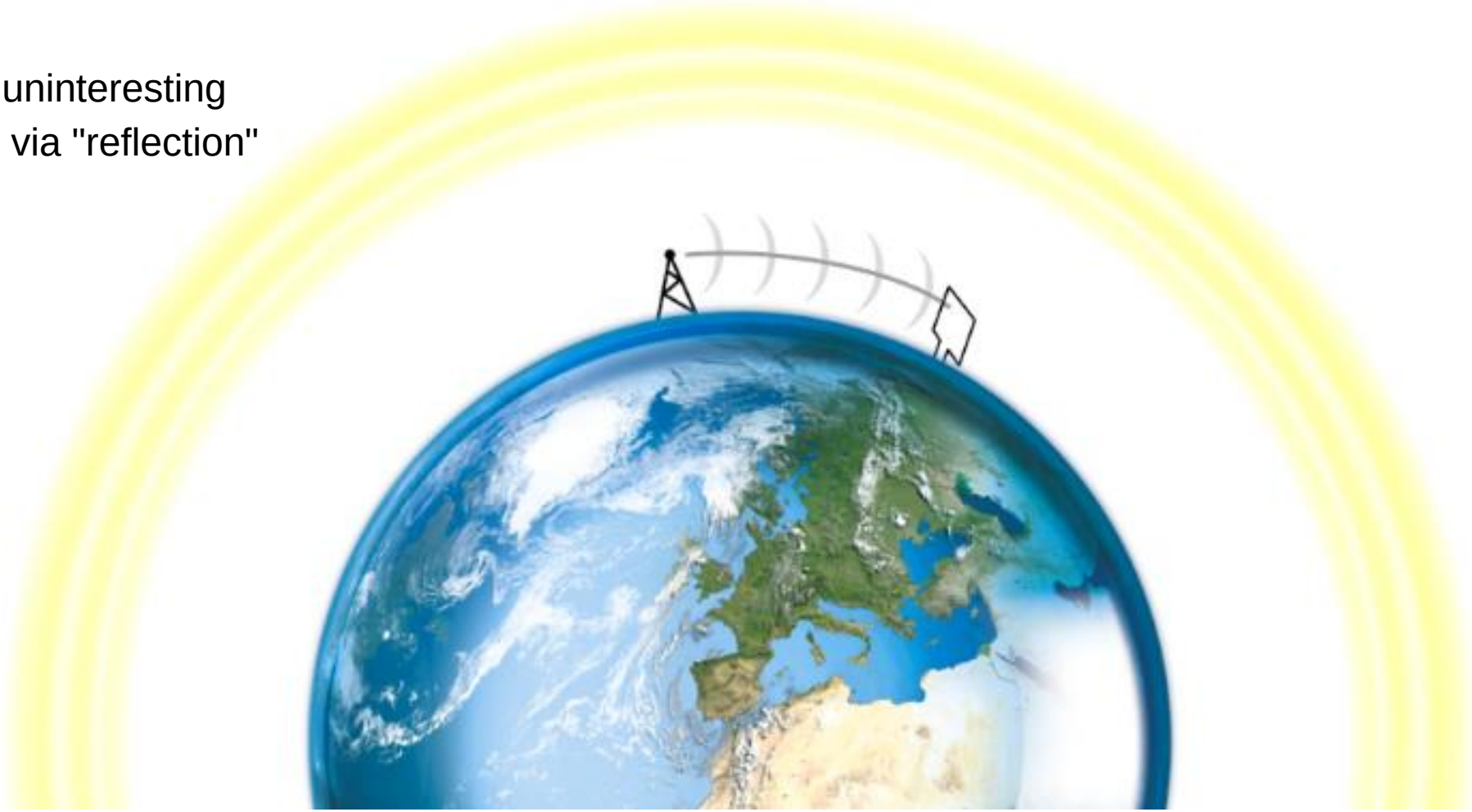
- !!! Screenshots from previous day (color plot and a 24hr curve)
- quiet vs. oscillating segments suggest diurnal dependence





The way of the signal

- direct (or ground) waves uninteresting
- higher-order (sky) waves via "reflection"
- rays gradually refracted
- paths sum up



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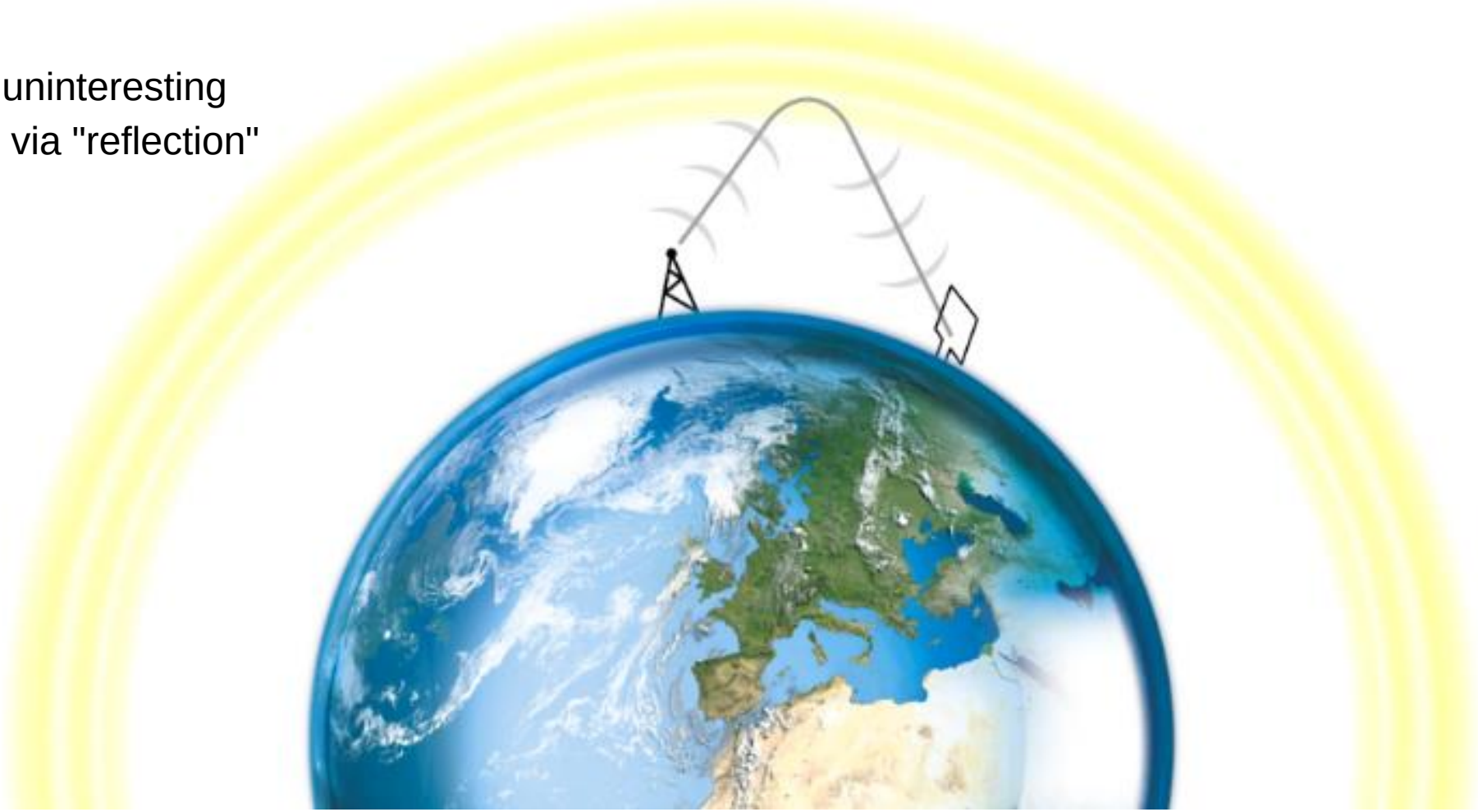

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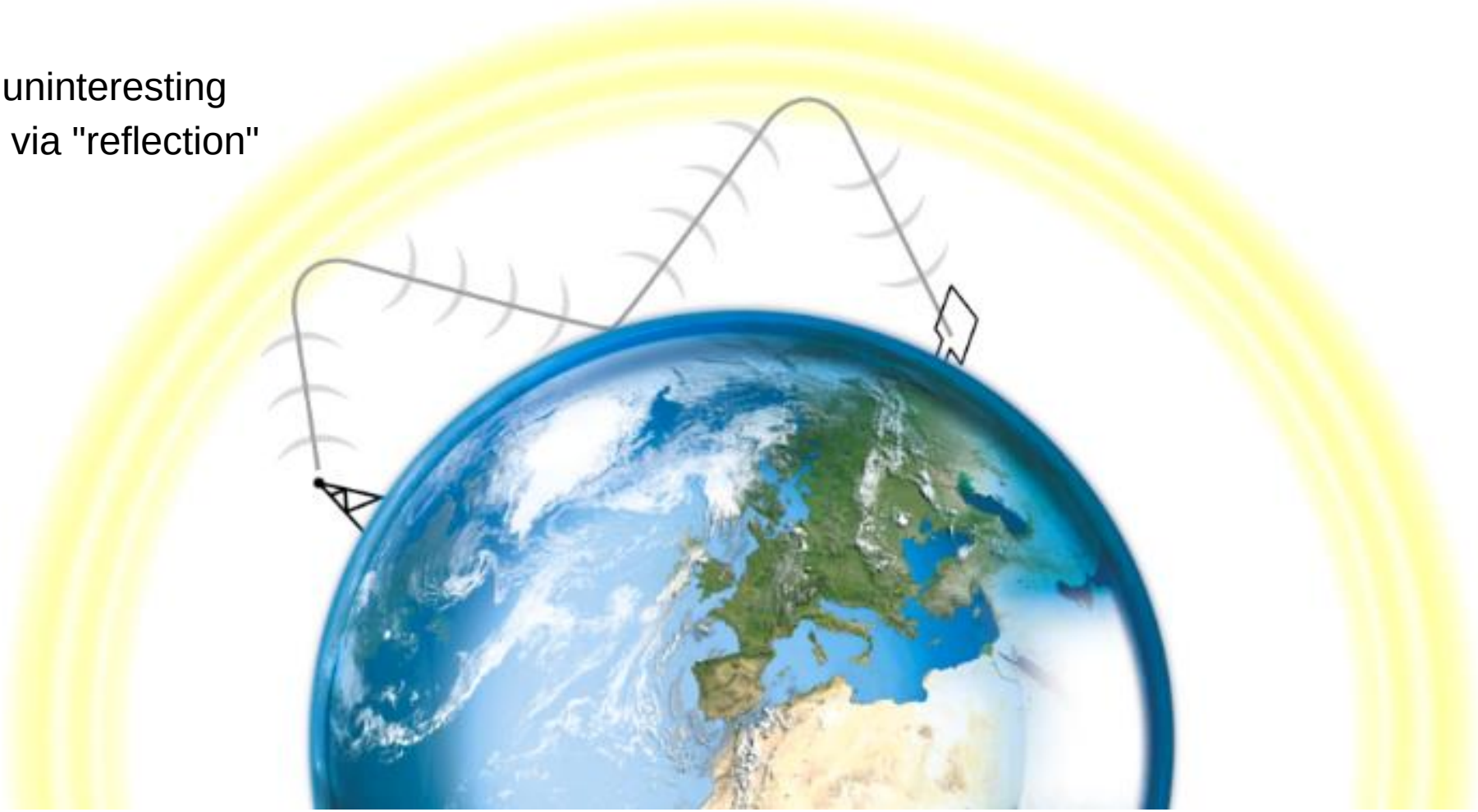
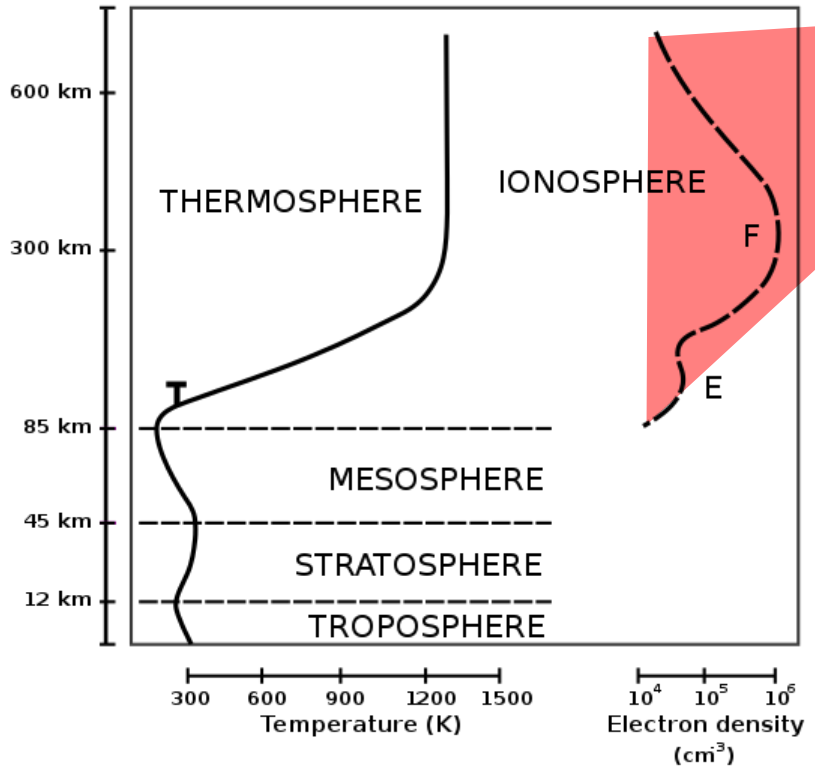
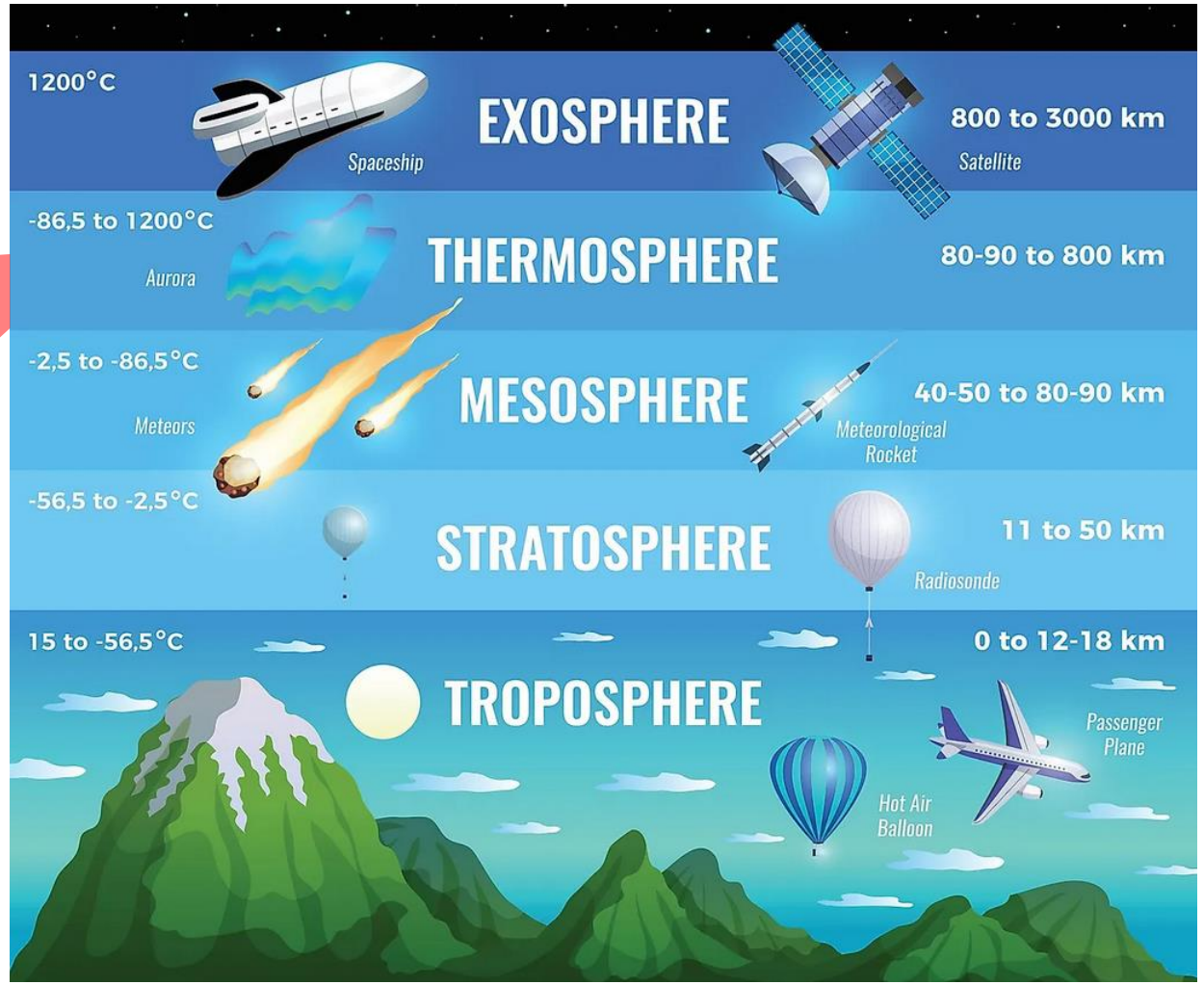


Atmospheric layers

lower thermosphere = ionosphere



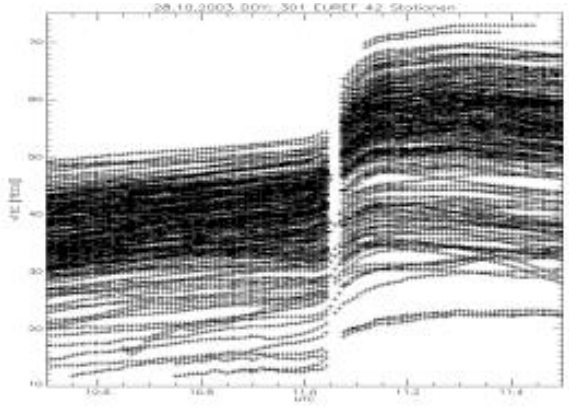


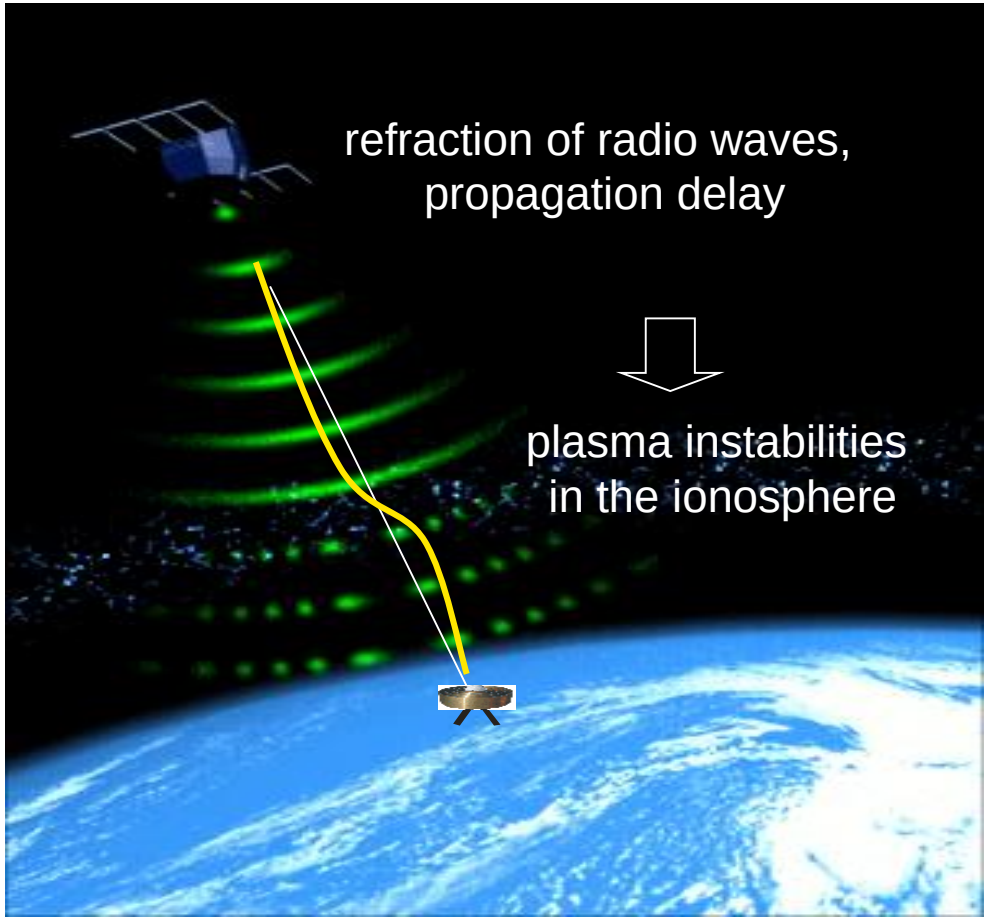
A kind of distorting filter

- plasma (ionized gas) causes a delay of radio signals
  → pretending excess in distance between satellite and site
- plasma instability causes signal strength fluctuations and defocussing of the signal
  → possible loss of the signal

➔ challenge for navigation, communication, Earth observation

➔ interplay between solar irradiation and ionosphere





Composition of the ionosphere

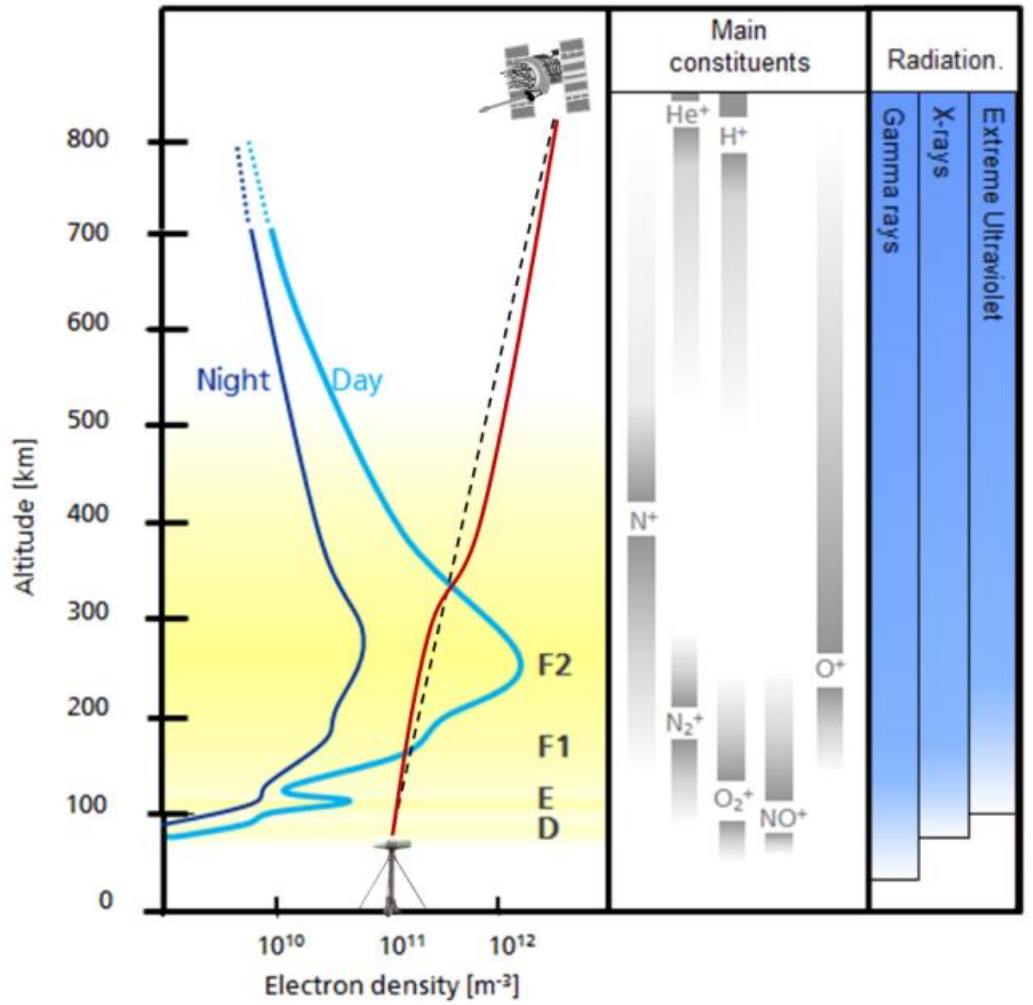
- via photoionisation neutral gas is split into electrons and ions (plasma)
- monitoring via GNSS → VTEC

F region (150 - 500 km)
- ionisation by EUV (20 to 90 nm)

E region (90 - 150 km)
- ionisation by EUV (80 to 102.7 nm)

D region = "VLF mirror"

D region (60 - 90 km)
- ionisation by Lyman-α (121.6 nm) and soft X-rays (below 1 nm)



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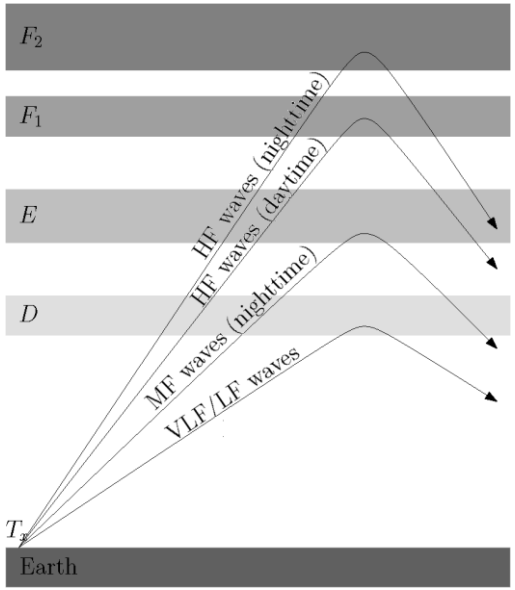

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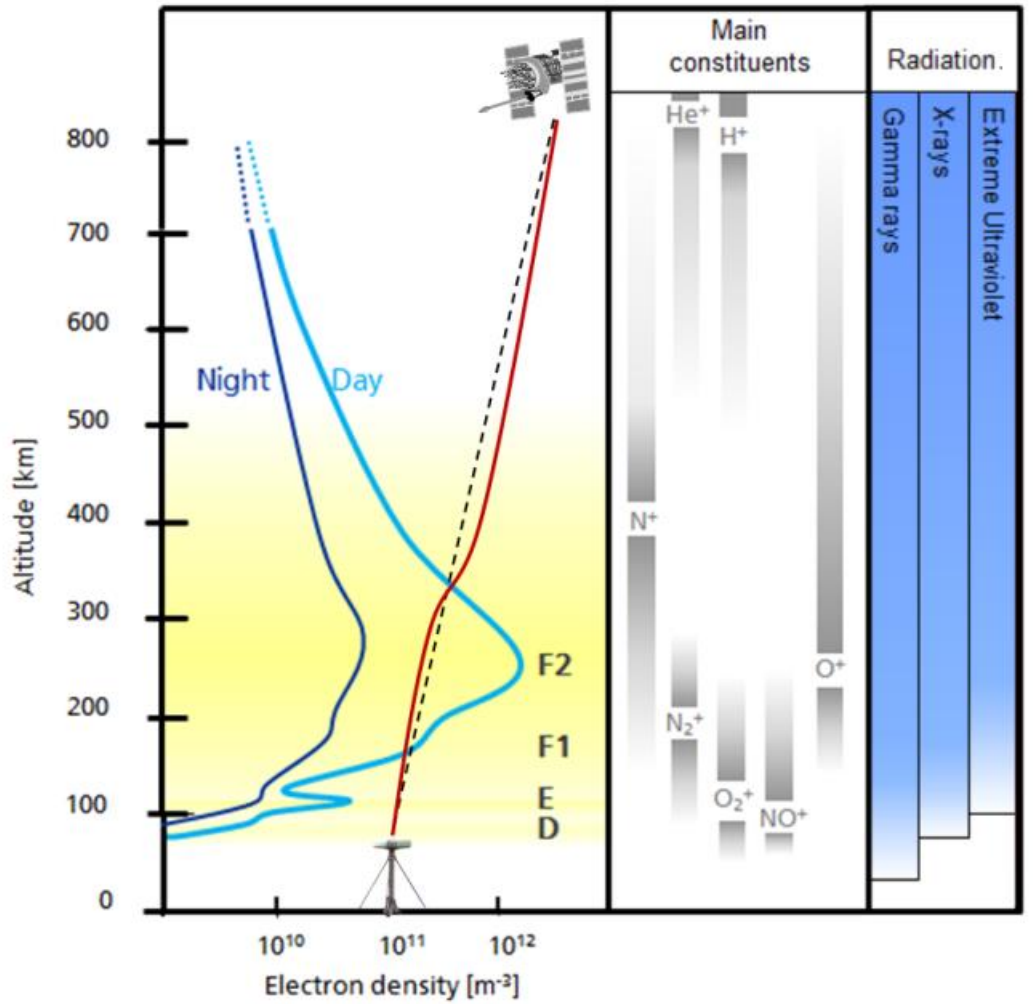
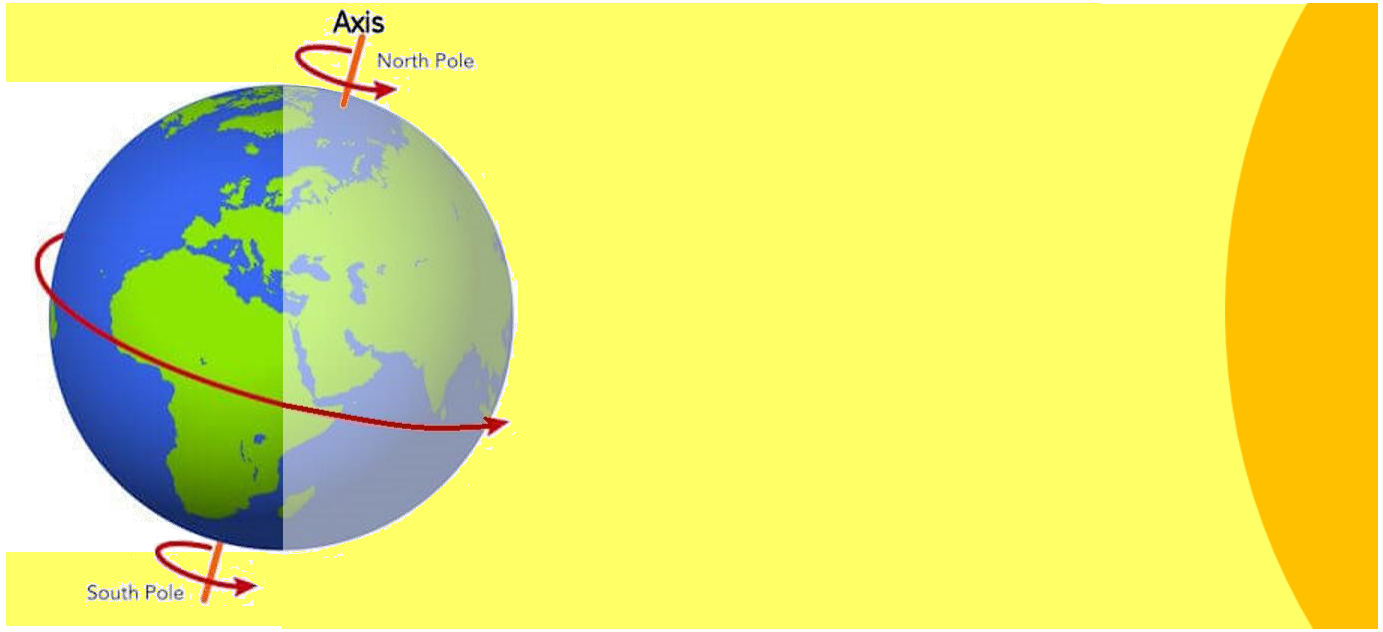
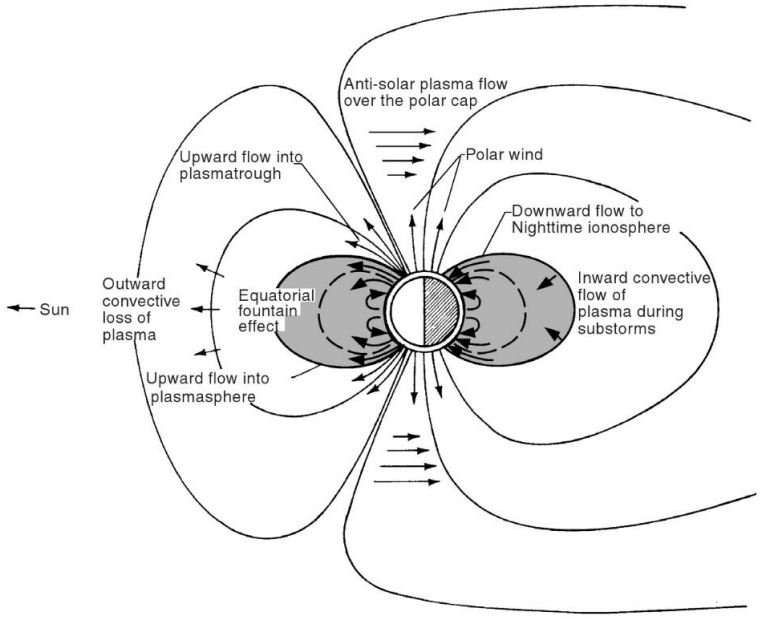
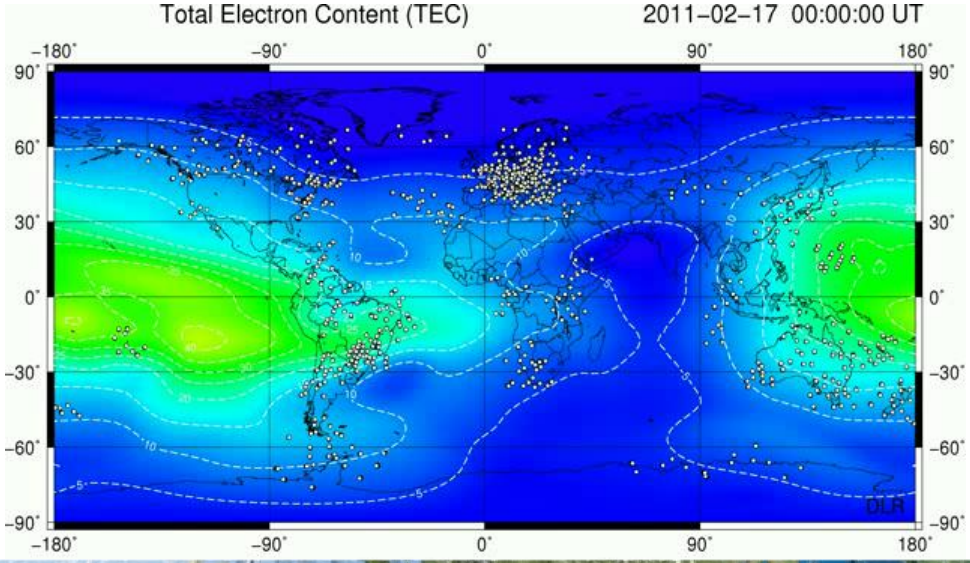


Earth's rotation







- spinning with a 24 hr period → diurnal variation
- only spotlighted parts → dayside affected
- varying striking angle → non-constant trend
- tilted axis → different day lengths

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Tasks for processing measurements

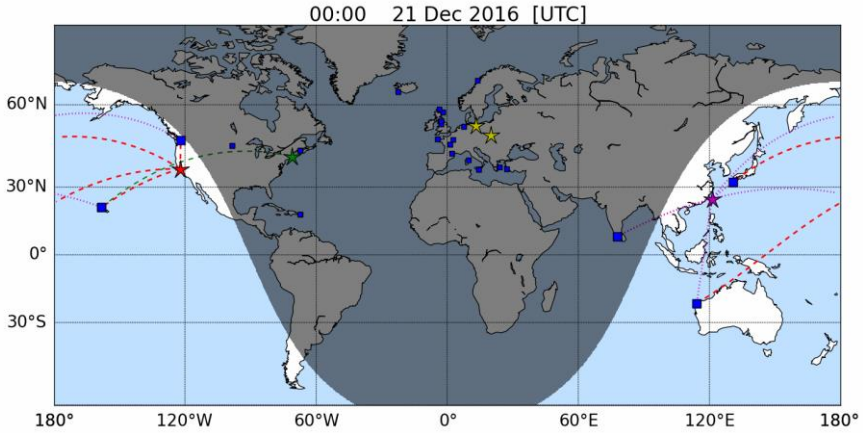
- Where are your Tx and Rx?

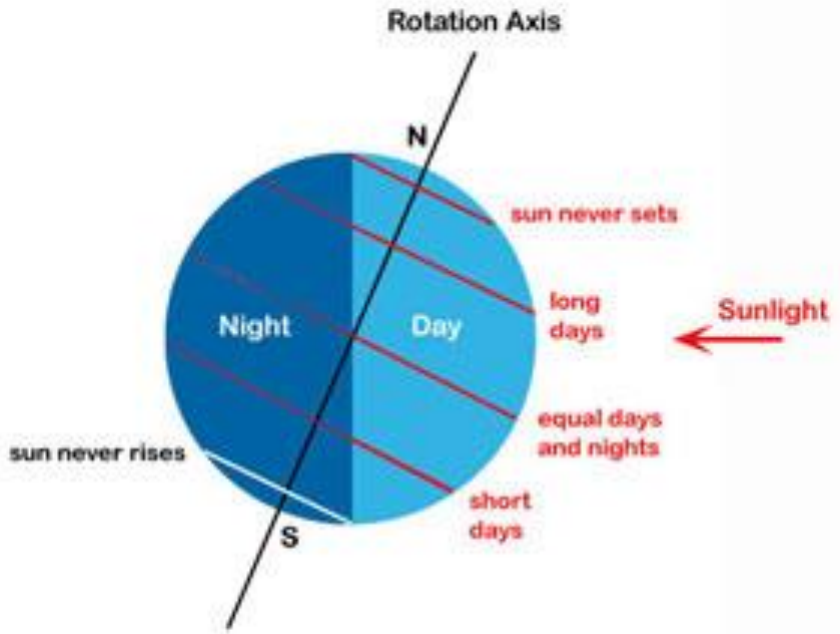
- When is your path on the dayside?
- How to throw away the night?
  → Find a strategy.

- Where is the zenith?
  → Plot the "noon" curve.

Useful packages in Python:

- geographiclib, geopy, haversine
- ephem, astral, skyline





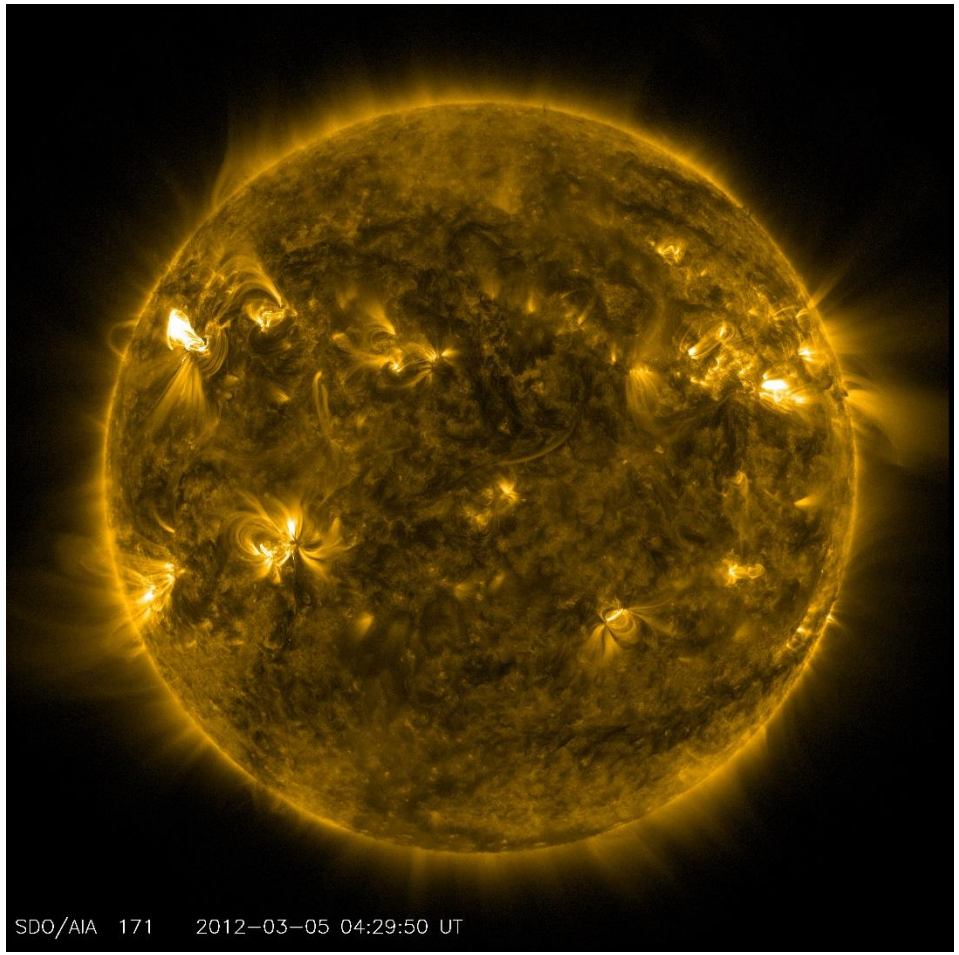
Disturbances

Expectation vs. reality

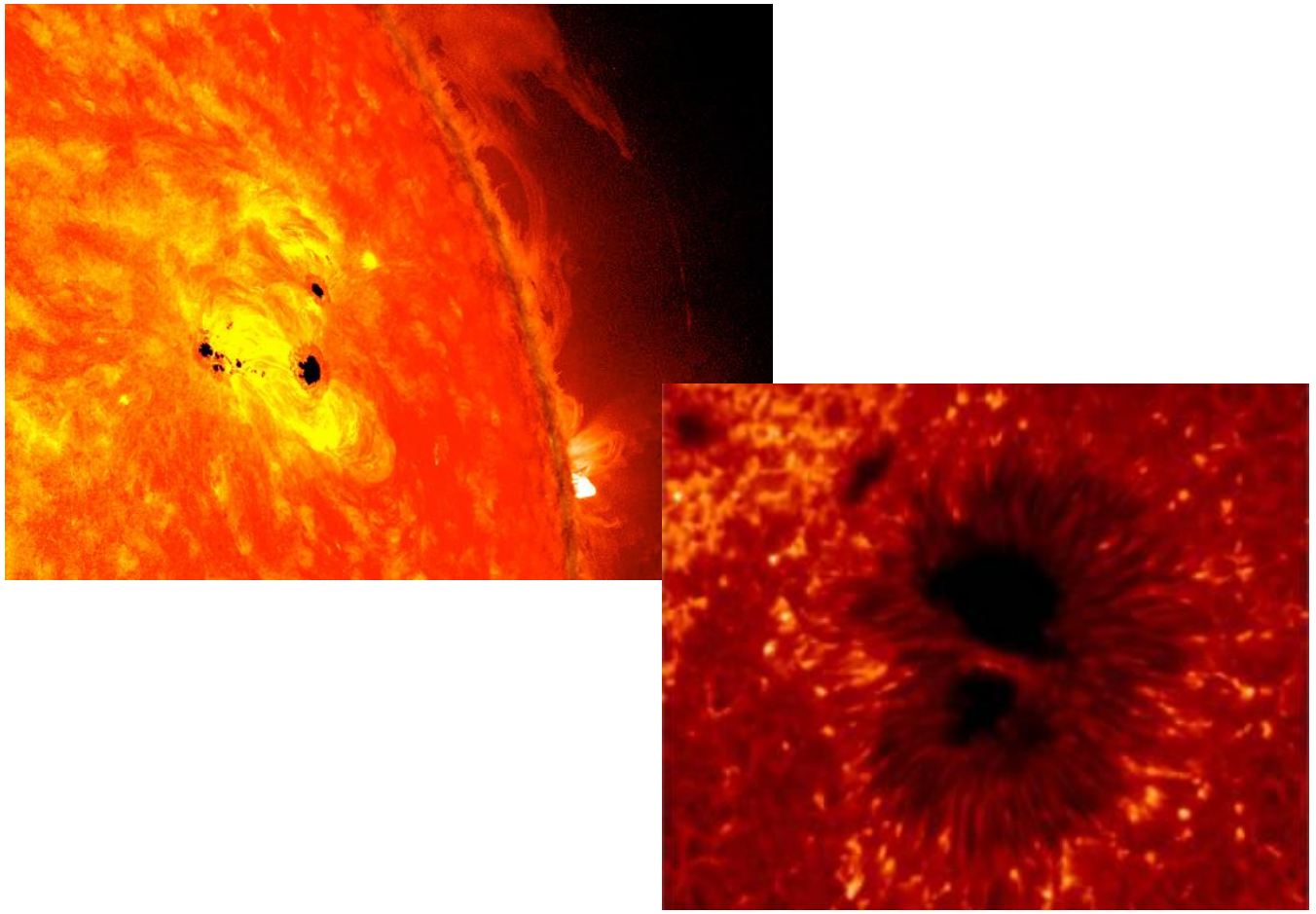
Daylight ionosphere is quite stable (small fluctuations observed as noise)

→ Impacting radiation from the Sun may vary!

The Sun

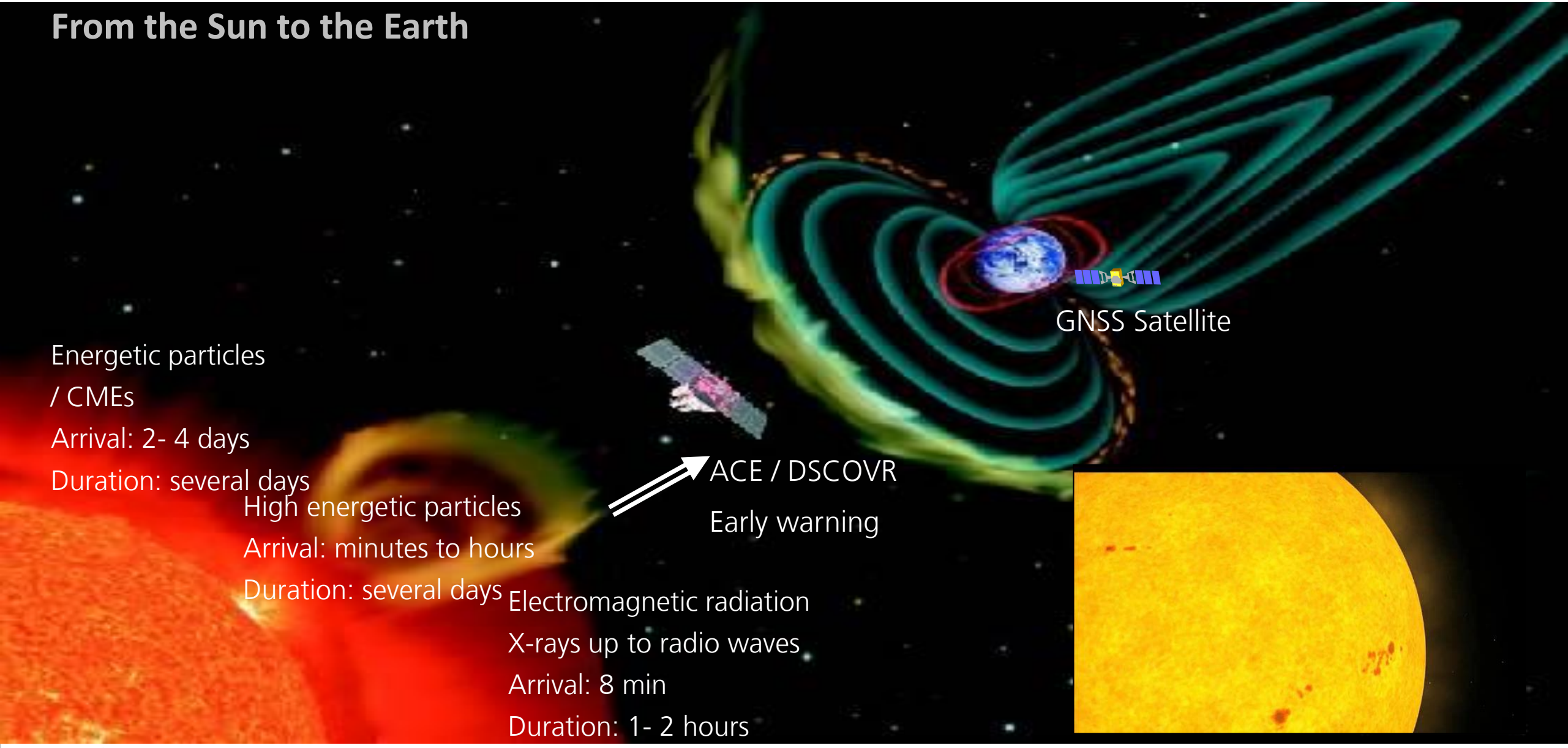


Source: NASA/SDO/AIA

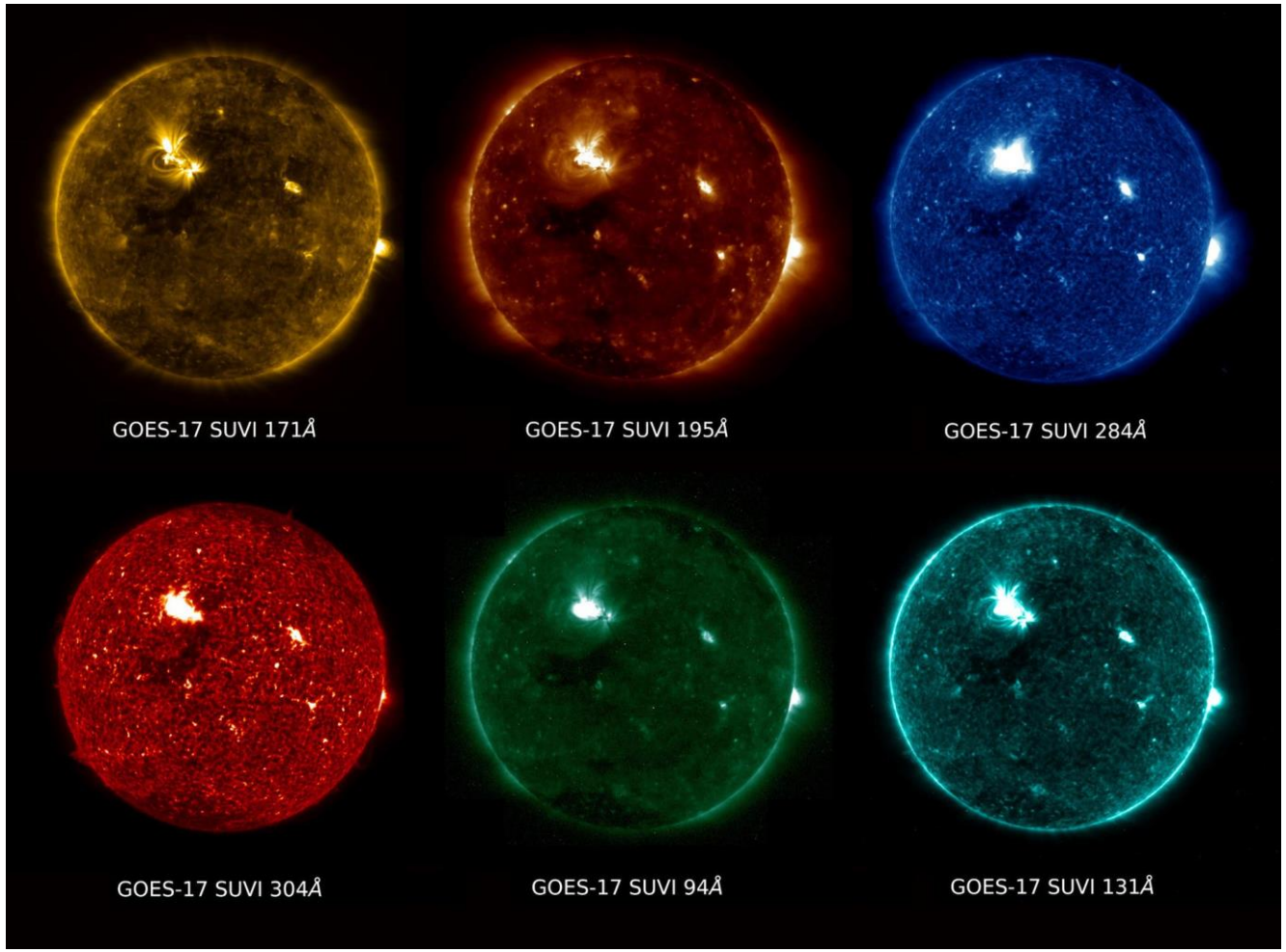


Sources: NASA/SDO/AIA/HMI/Goddard Space Flight Center and NAOJ/NASA/Hinode

From the Sun to the Earth

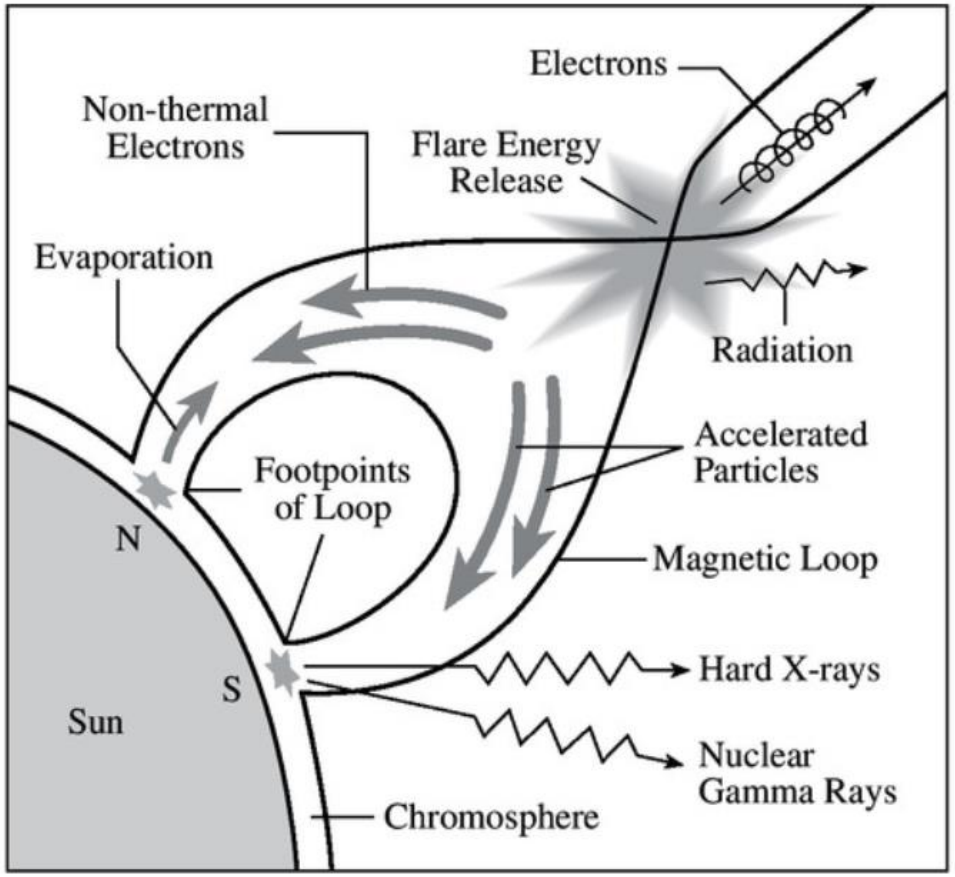


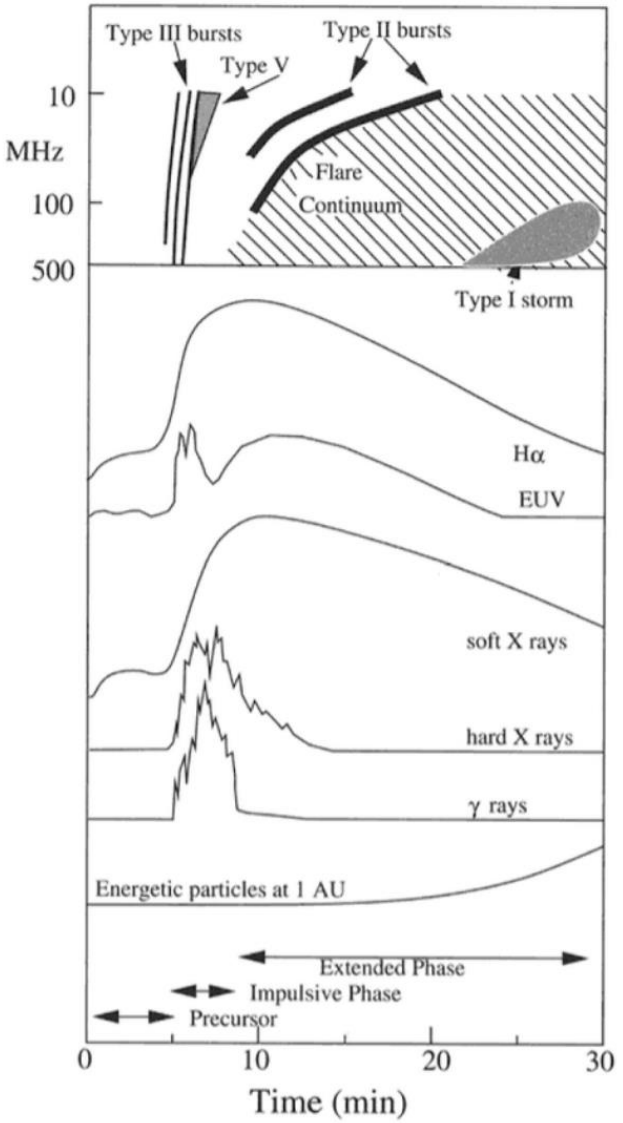
Solar flares



Snapshots of solar flares
Sources: GOES-16 and GOES-17

Solar flares

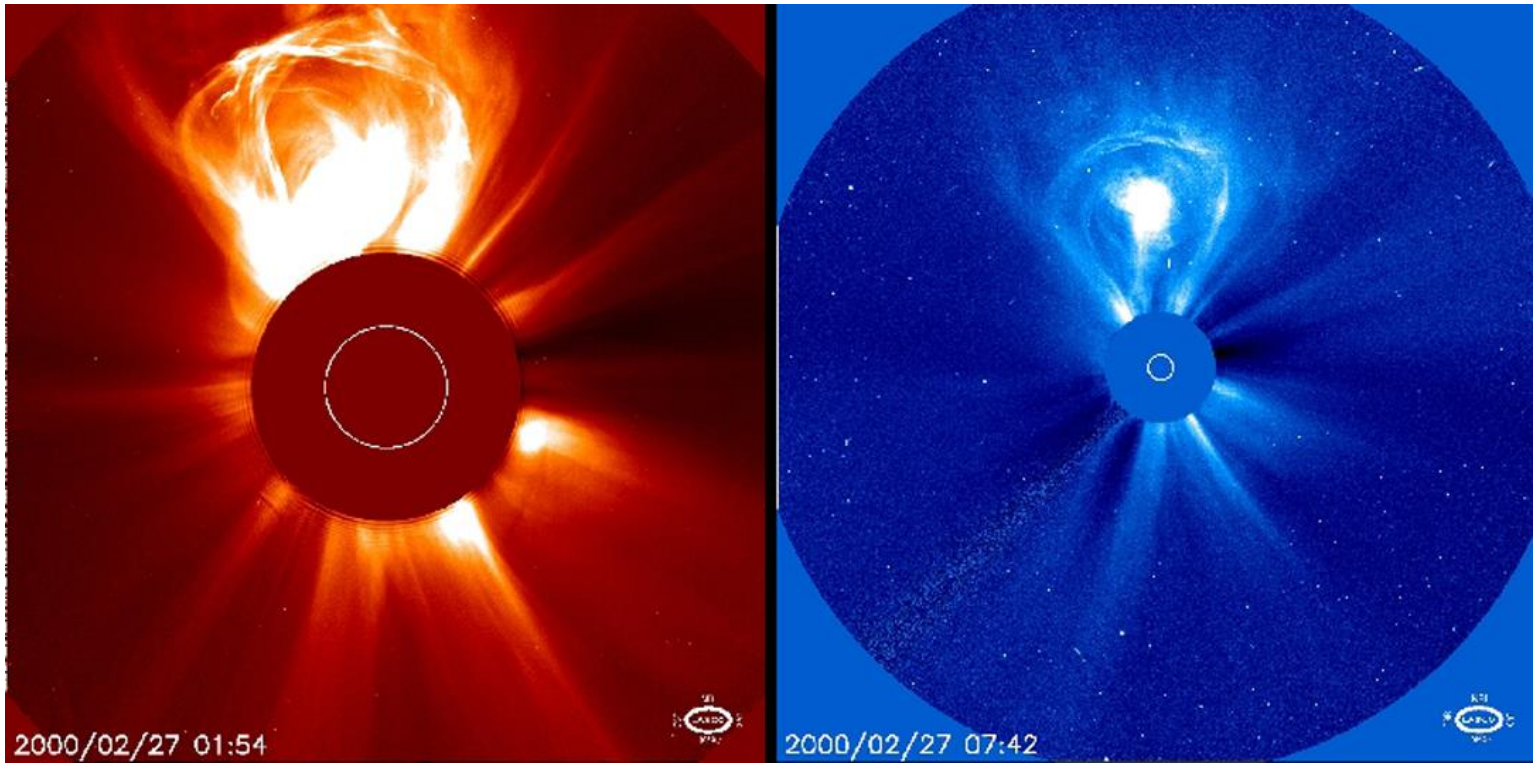




Left: Standard flare model. Right: A flare in different wavelength.

➔ X-ray flares ↔ ionosphere D layer ↔ VLF signal

Coronal Mass Ejections



CME on 200-02-27 taken by SOHO LASCO (ESA&NASA/SOHO)

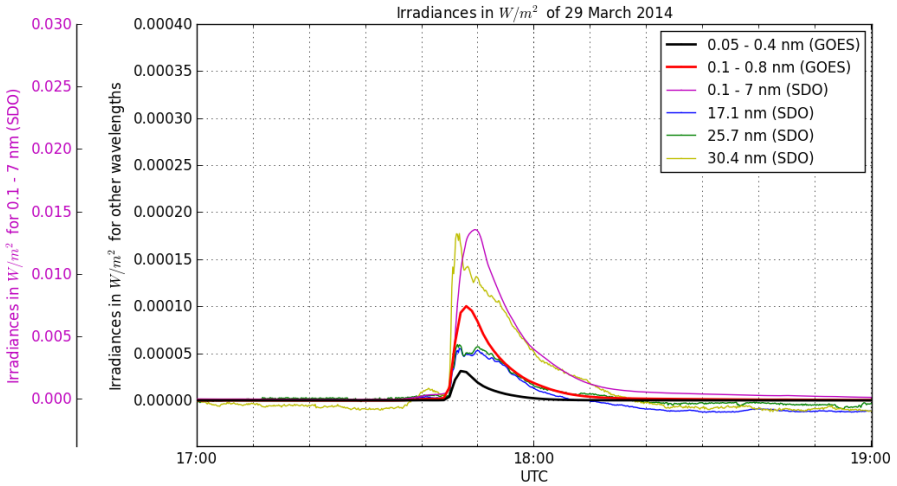
Source …

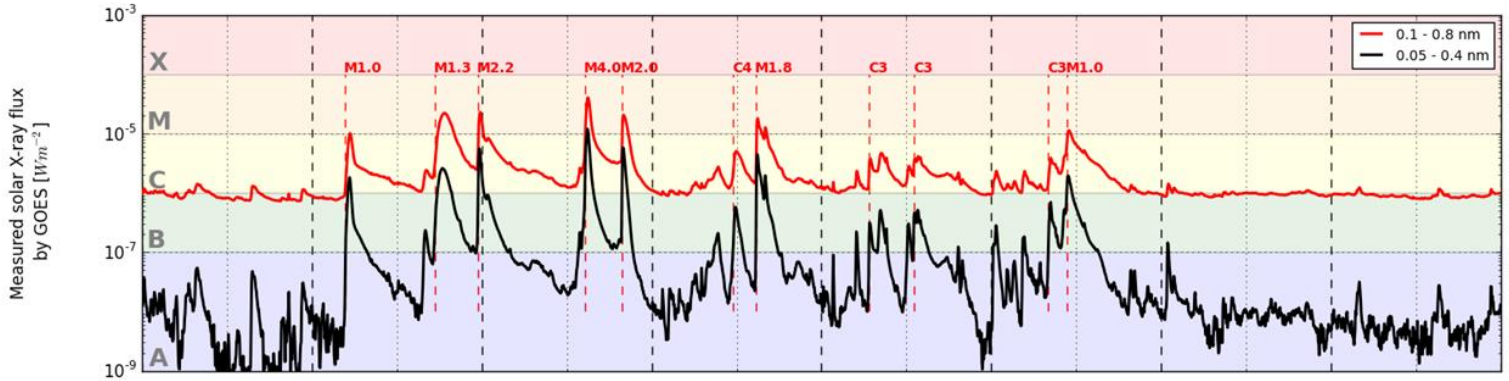
… can be measured directly only in space

GOES – Geostationary Operational Environmental Satellite

- network for monitoring Earth from above
- also X-ray detectors before ionospheric influence

- stable basic level coming from Sun
- events like flares distributed over the spectrum





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… and effect

… can be observed ground-based:

Radiation bursts at EUV and X-ray considerably increase plasma density in ionosphere

→ reaction visible in VLF measurements

What about the "normal" impact?

- no D layer in nighttime!
- non-constant progression in daytime