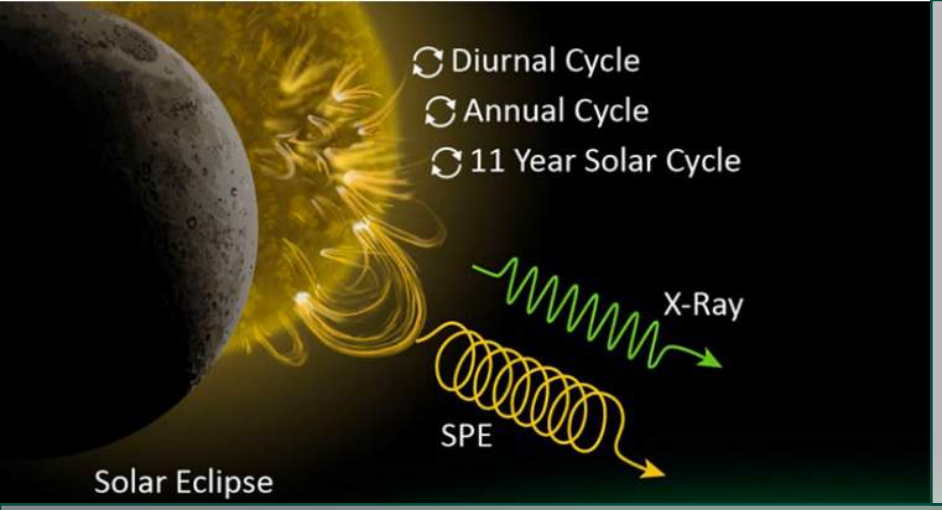
VLF FOR IONOSPHERIC STUDIES (VLF4IONS)

Carine BRIAND, Pauline Teysseyre (PhD)

LESIA/Observatoire de Paris-PSL, CNRS, Sorbonne Université, Univ. Paris Cité

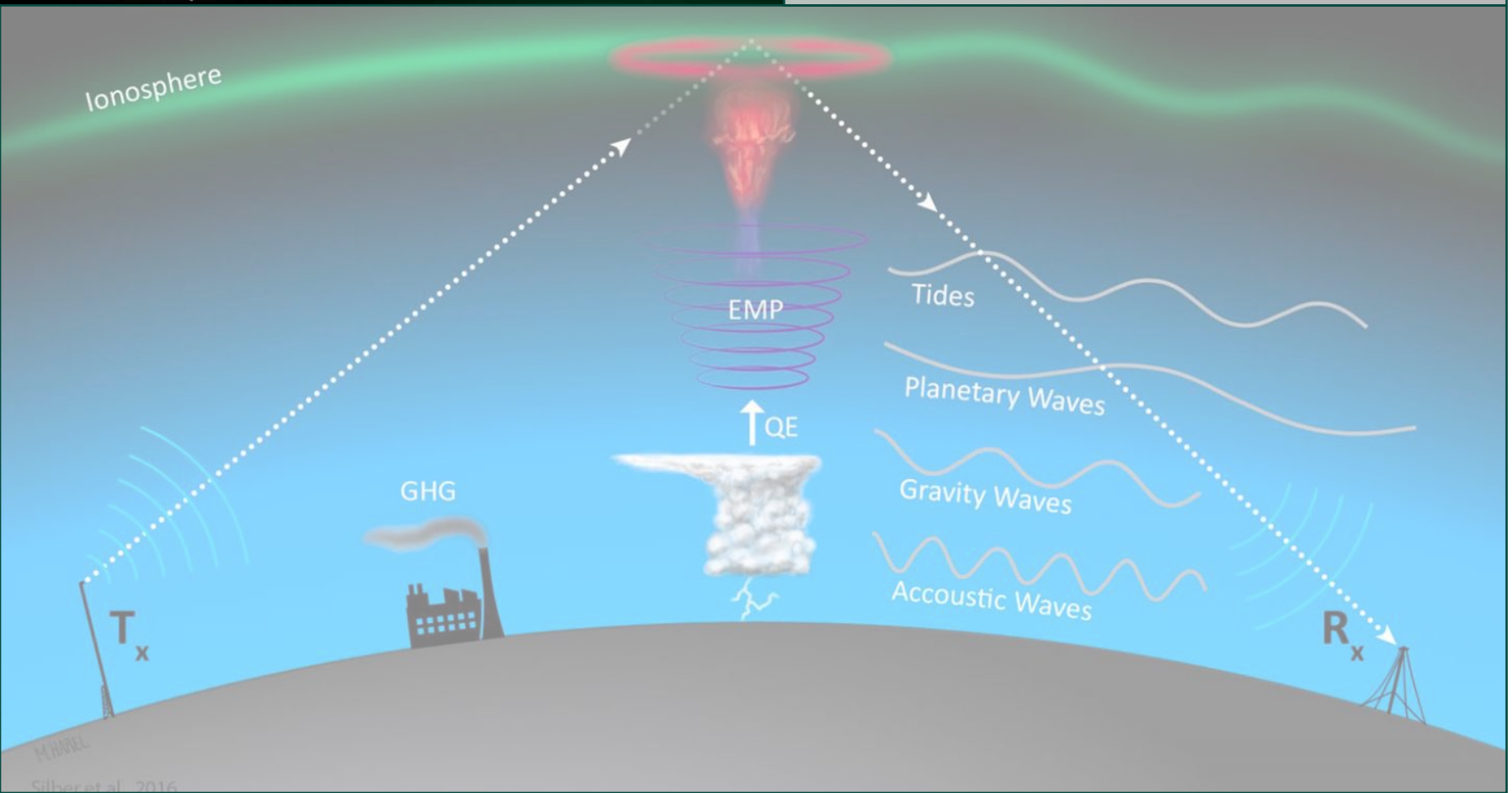
Four sources of ionospheric forcing



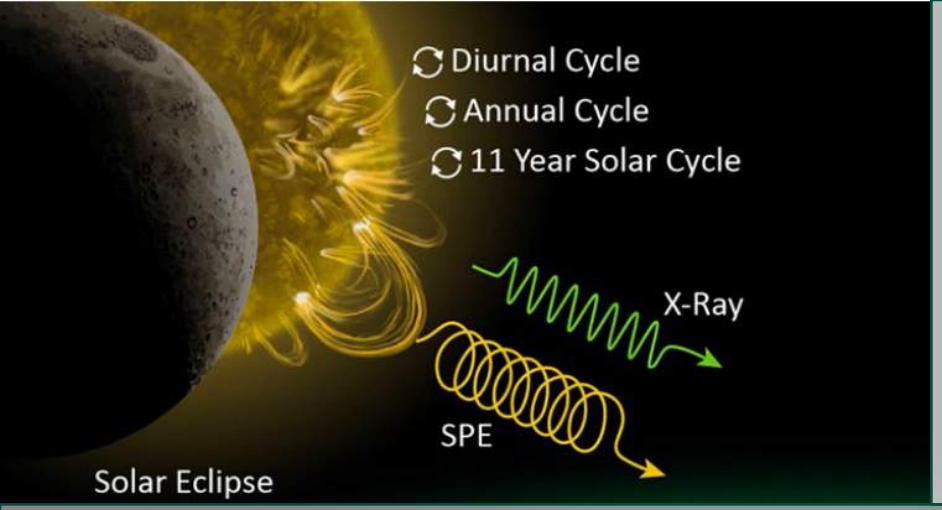
γ-Ray

1° The Sun

- EUV, X-ray
- Time scales: From 11 years to minutes
- Spatial extent: large (sunlight face of the Earth)



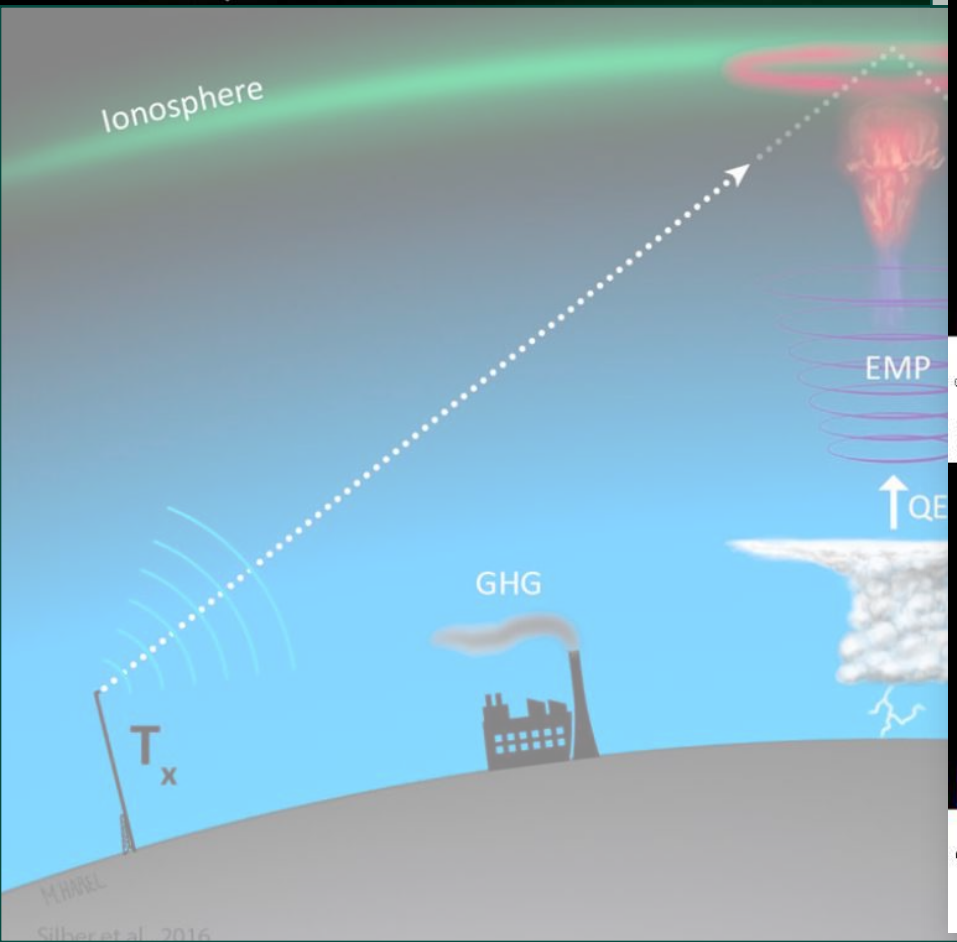
Four sources of ionospheric forcing

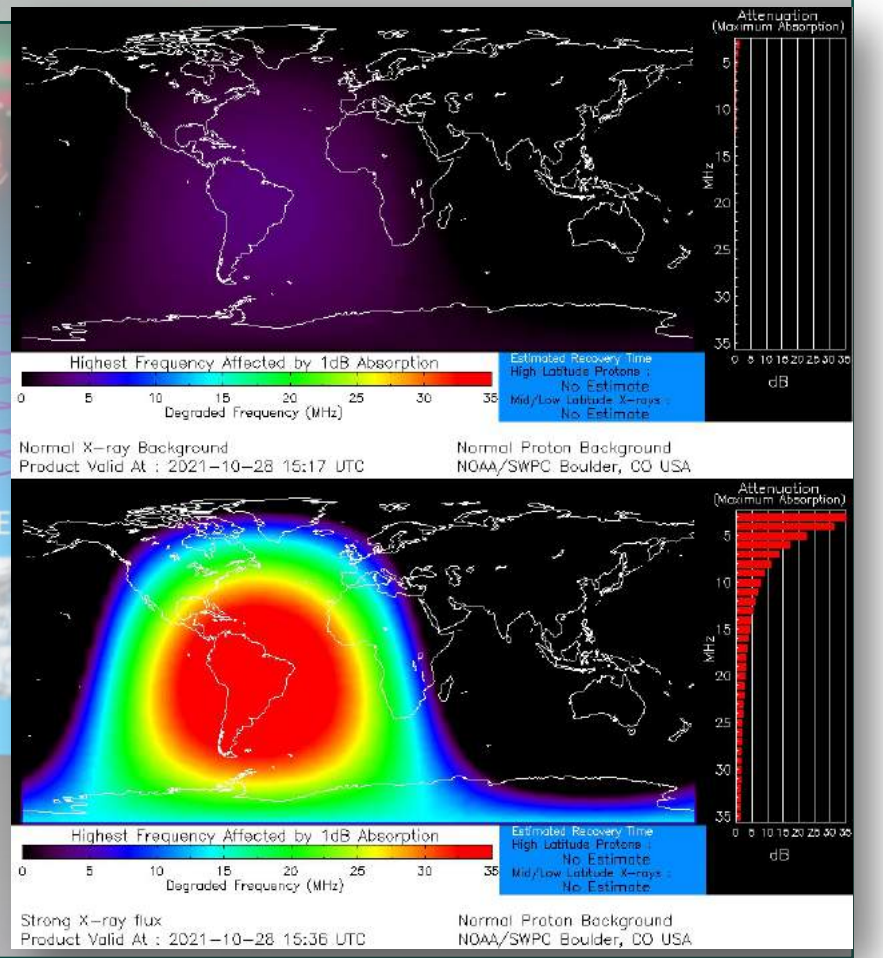


γ-Ray

1° The Sun

- EUV, X-ray
- Time scales: From 11 years to minutes
- Spatial extent: large (sunlight face of the Earth)

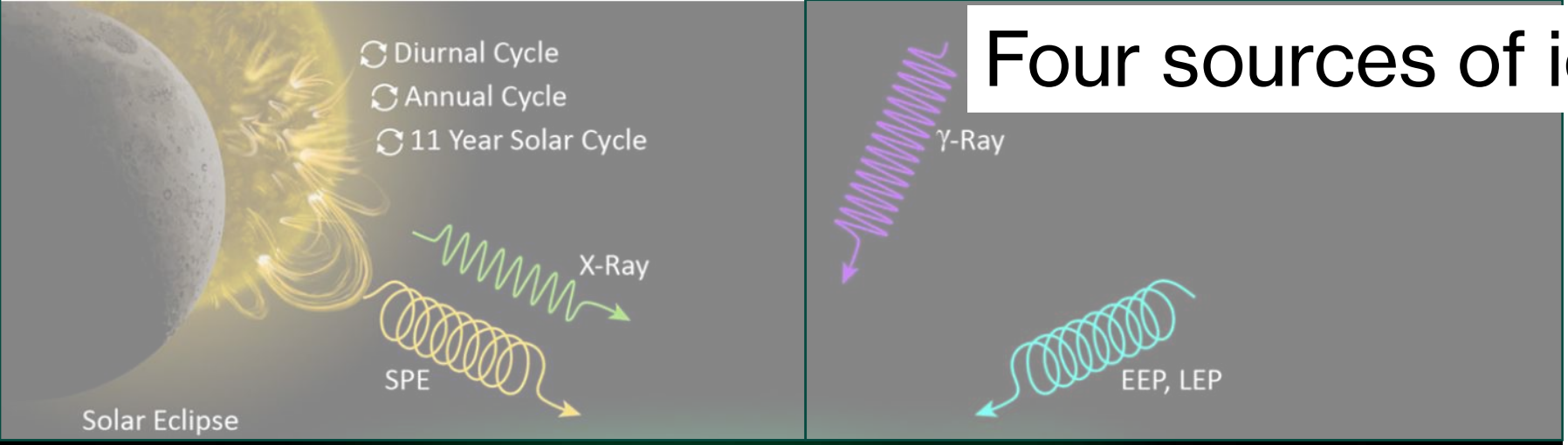


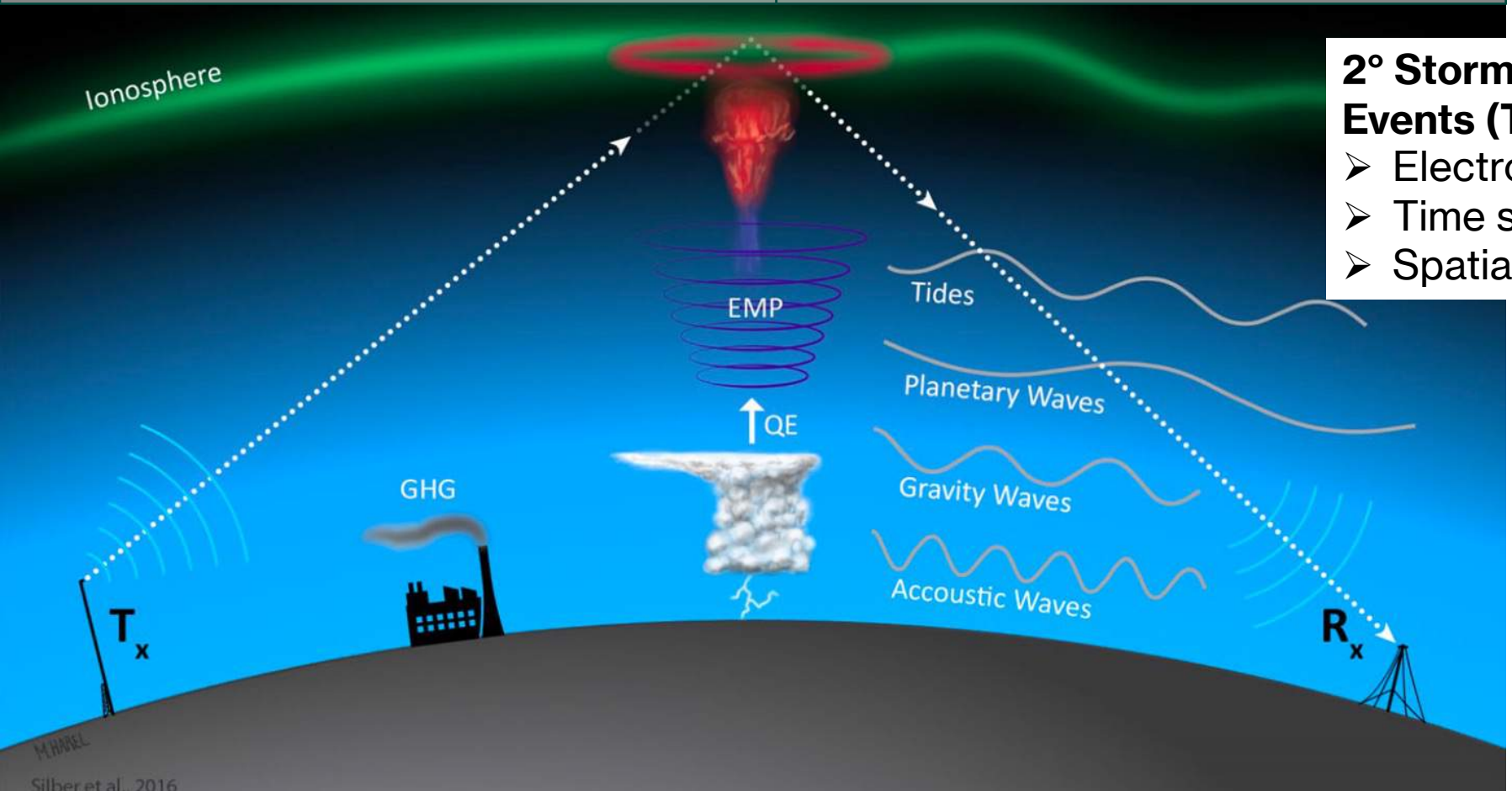


Responsible for strong HF absorption → Aircraft

(+ S/C drag increase)

Four sources of ionospheric forcing

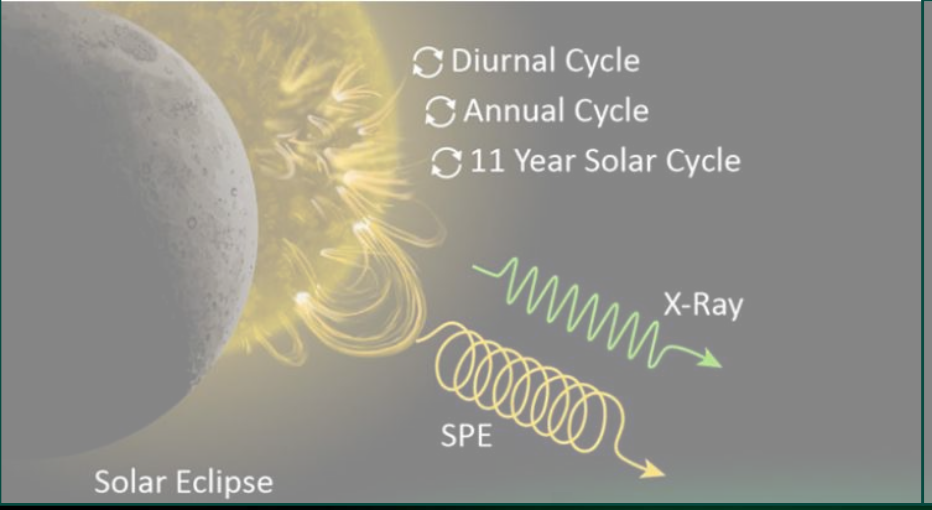


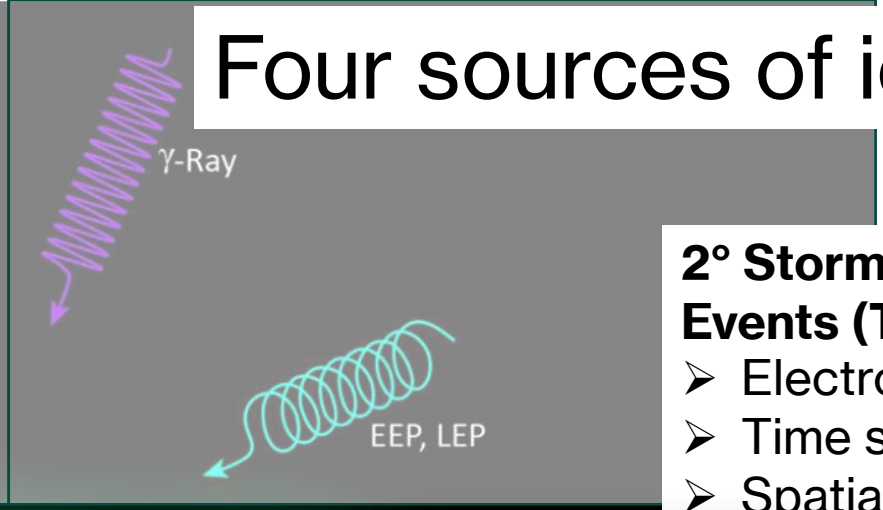


2° Storm area : Transient Luminous Events (TLEs)

- Electrostatic discharges + heating
- Time scale: << 1s
- Spatial extent: hundreds of km

Four sources of ionospheric forcing





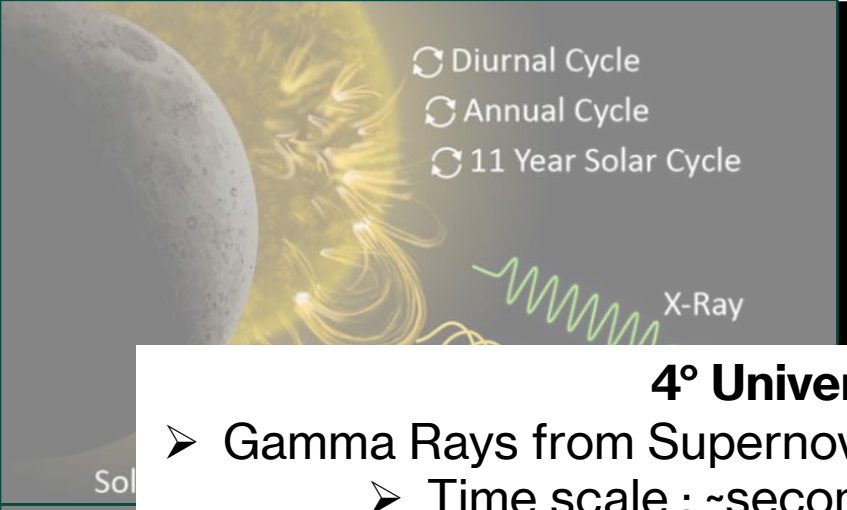
2° Storm area: Transient Luminous Events (TLEs)

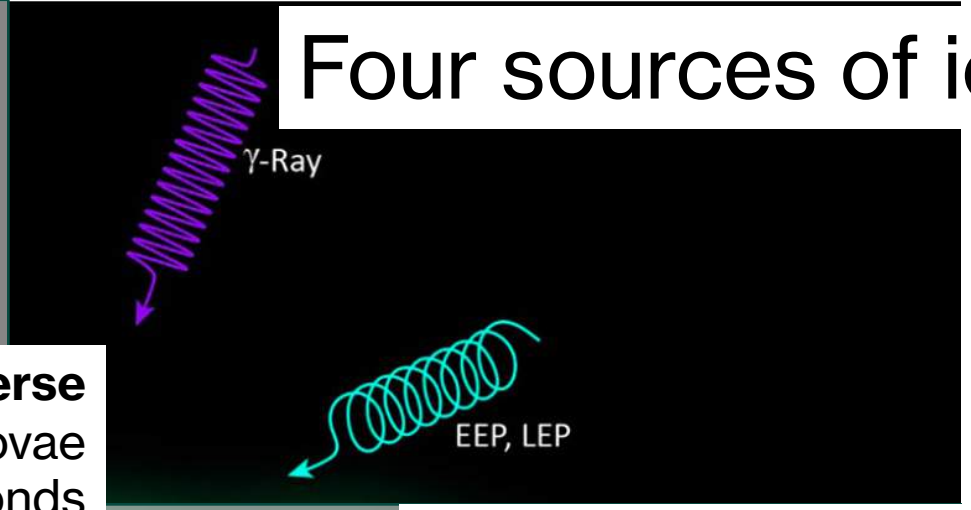
- Electrostatic discharges + heating
- Time scale: << 1s
- Spatial extent: hundreds of km

Sprites, Elves, Giant Jets
Power CG discharges (250kA)

Climate change: more powerful storms expected

Four sources of ionospheric forcing



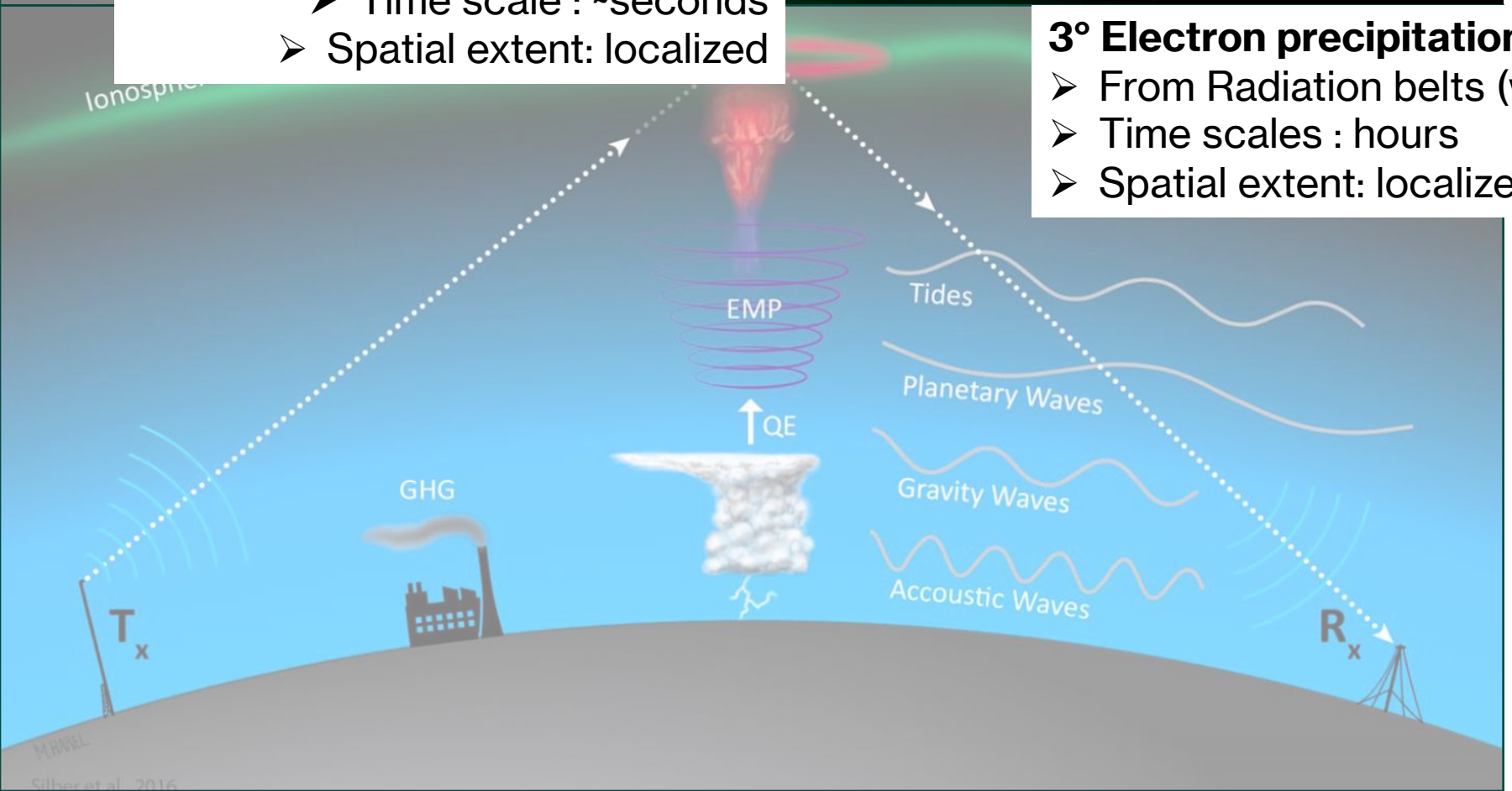


4° Universe

- Gamma Rays from Supernovae
  - Time scale : ~seconds
  - Spatial extent: localized

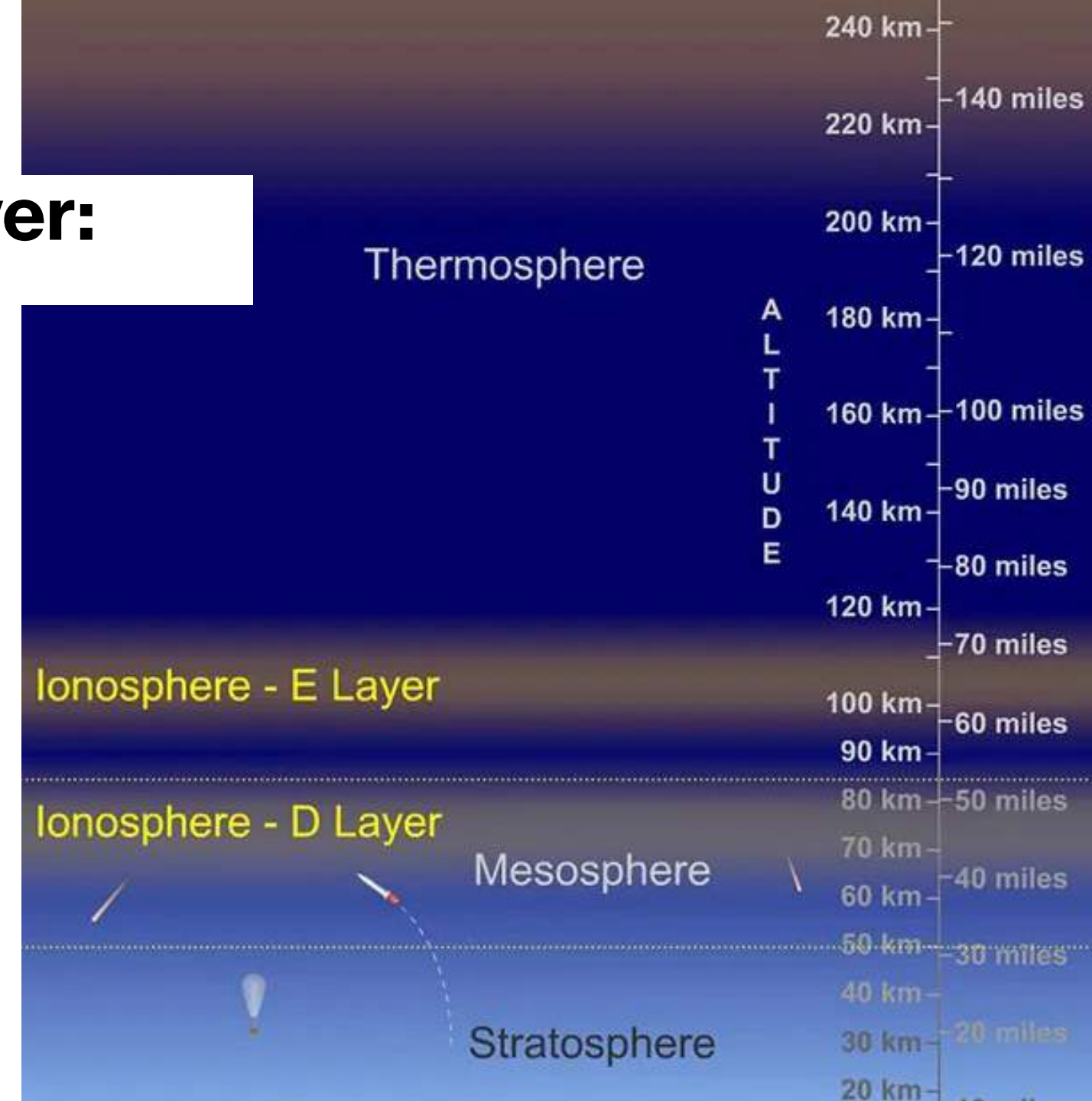
3° Electron precipitation

- From Radiation belts (whistler waves from lightning)
- Time scales : hours
- Spatial extent: localized to the polar regions



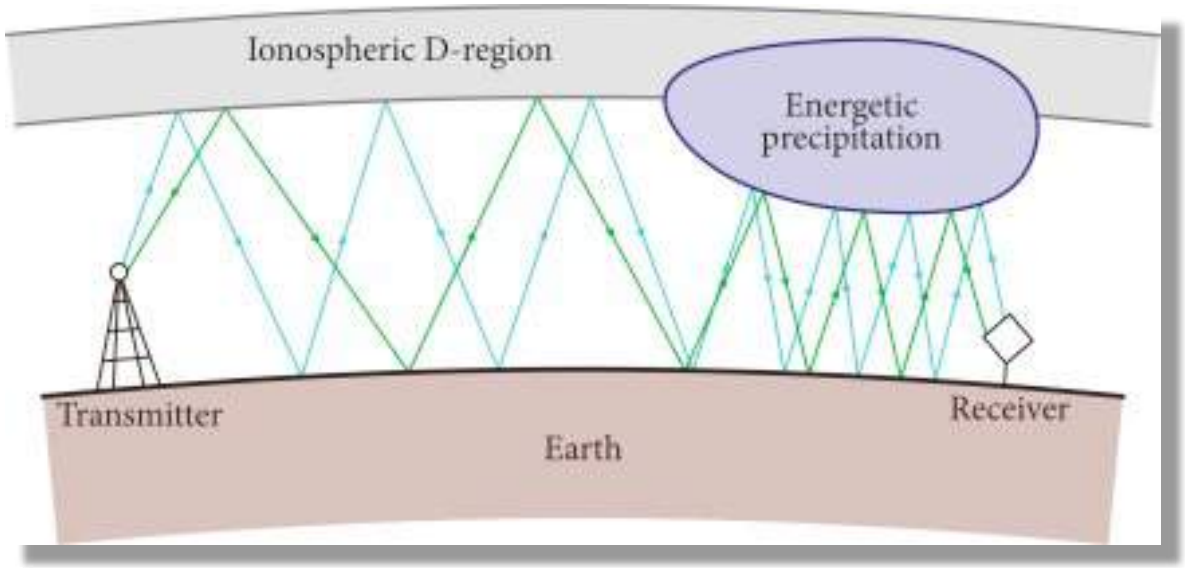
Observing the D-layer: the *ignosphere*

- D-layer: 60-90km
- Too high for balloons
- Too low for satellites
- **VLF waves propagation:**
  - VLF propagates thousands of km;
  - Continuous survey: revisit rate of S/C (1.5h) is too long compared to flare's lifetime;
  - Ionosphere over oceans can be followed



Principle of VLF measurements

- VLF Transmitter (Tx) somewhere on the ground
- VLF receiver (Rx) far away (hundreds to thousands of km away)
- VLF wave propagates in the **waveguide** formed by the **ground and the D-layer**
- Any change of conductivity modifies the modes propagating inside the waveguide → change the signal at the Rx
    - Ground conductivity (soil moisture, city expansion, presence of lake/island along the path ...)
    - Ionosphere conductivity (electron content)



VLF4IONS PROJECT

VLF FOR IONOSPHERIC STUDIES

The first stone @Nancay

VLF4IONS project: a digest

SCIENTIFIC COMPONENT

I. Solar forcing
   a. Onset and time evolution: what relation with the forcing strength?
   b. Parameters that controls the relaxation?
   c. Propagation of the perturbation in latitudes
   d. Seasonal variation of the N/D transition: why ? ...

II. Lightning forcing
   a. TLE and lightning relationship
   b. What conditions favor the occurrence of TLEs ...

SOCIETAL COMPONENT (SPACE WEATHER)

Provide (quasi) real-time estimate of the ionospheric disturbance during solar flare

a. Spreading alert on flare occurrence
b. Estimate of flare strength (related to I.a)
c. Estimate of the disturbance duration (related to I.b)
d. Estimate of the spatial extension of the disturbance (related to I.c)

→ Long term, continuous monitoring worldwide (to catch ALL flares & many storm cells)

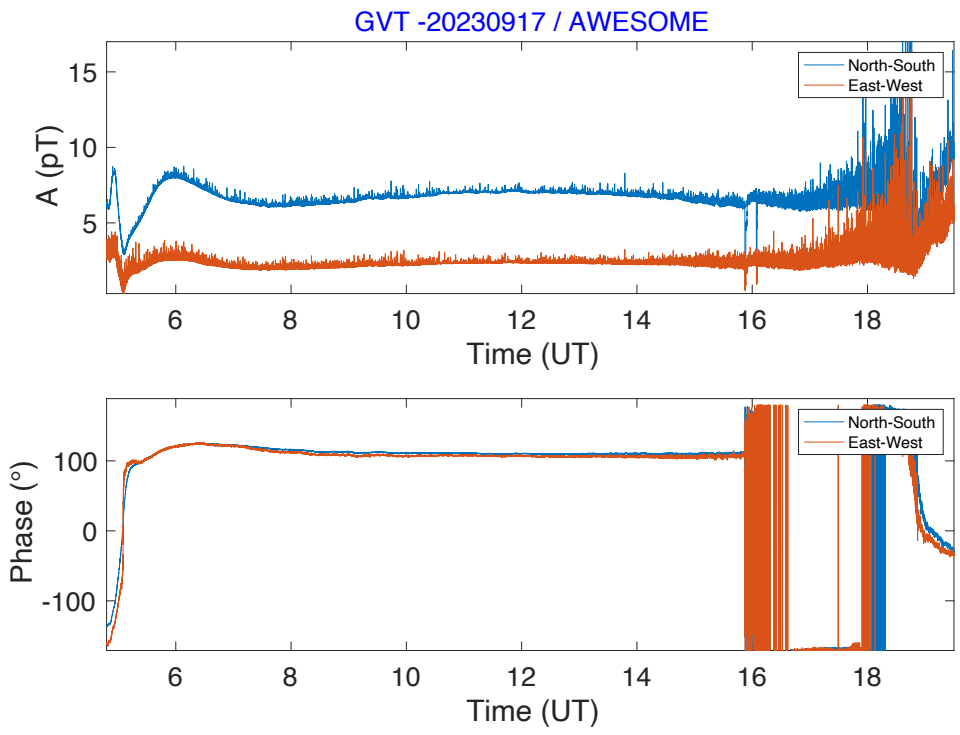
Instrument: AWESOME

- **Design and build by Georgia Univ.**
- Magnetic loop antenna to measure the B-field of the VLF wave
  - 4m diagonal base ; 2.5m high
  - GPS for accurate phase measurement
  - Line Receiver: signal amplification and processing
  - PC: signal processing + storage
- **Measure Amplitude and Phase**
- Running since June 2022

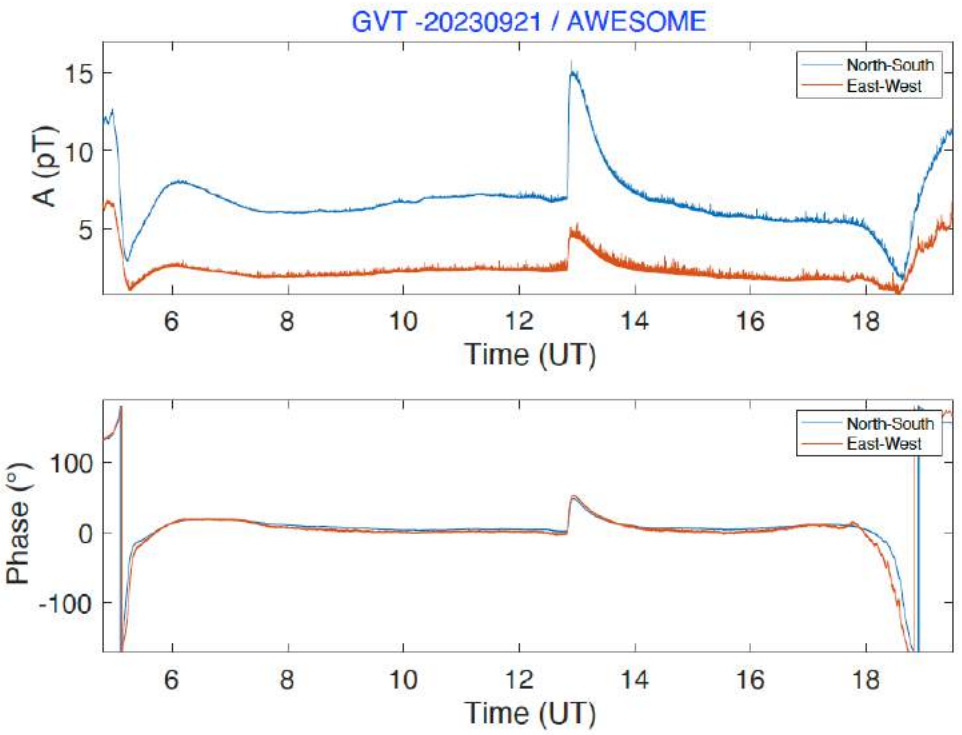
DATA: NARROWBAND

- At the frequency of the Tx (between 15 & 45kHz) +/-0.1kHz
- 7 stations simultaneously

Quiet day

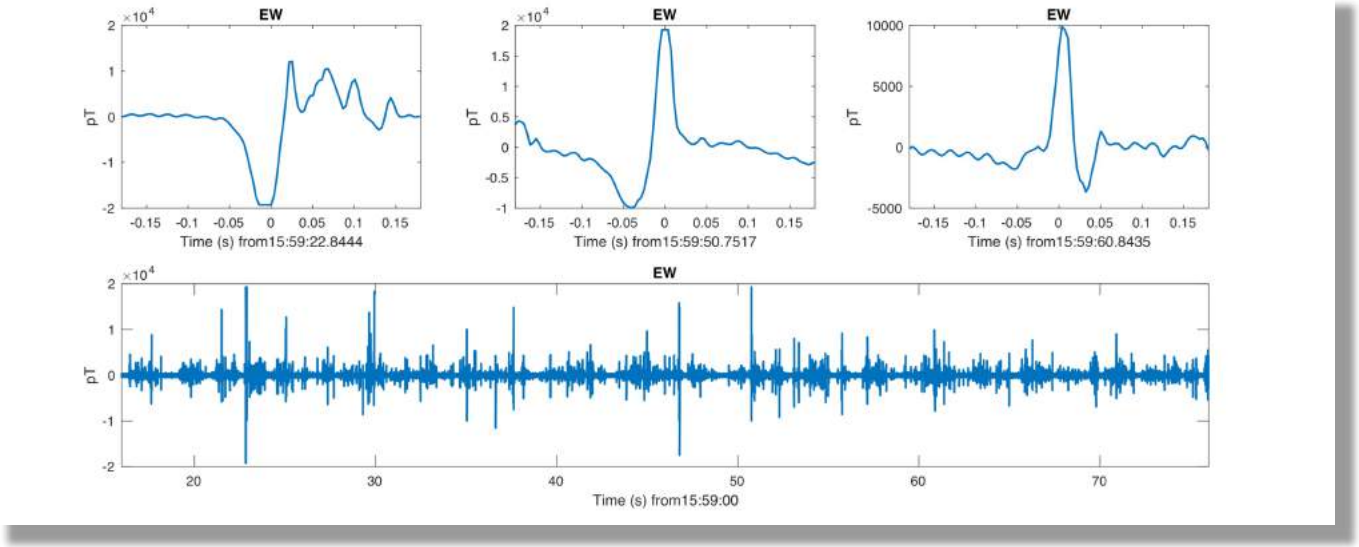


Moderate Flare (M8.1)

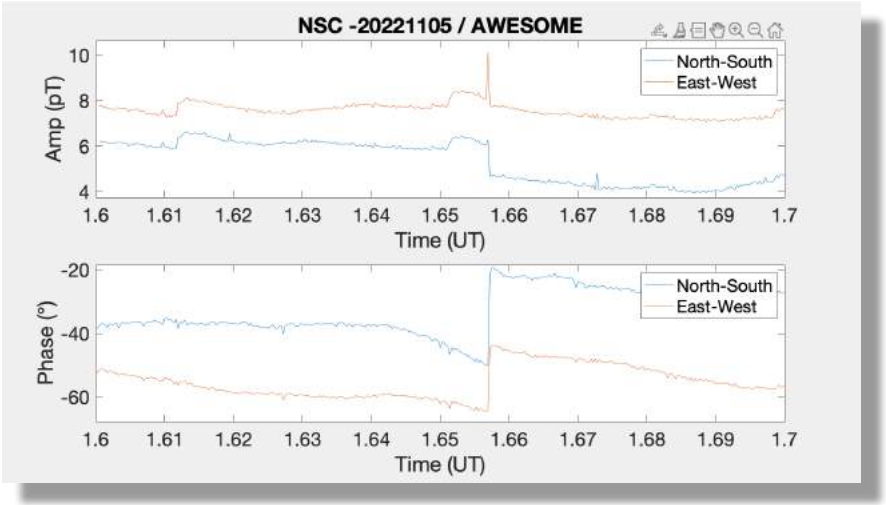


DATA: BROADBAND

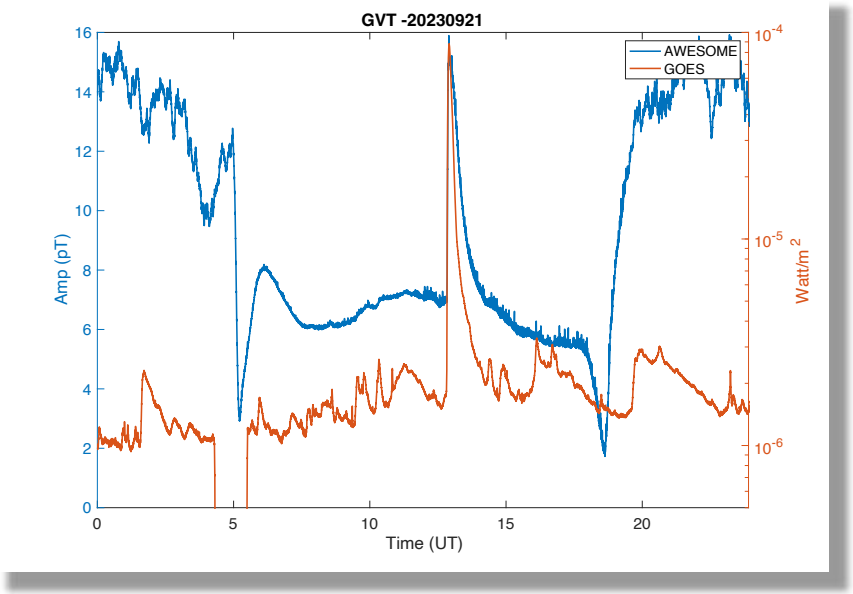
- Waveform @1MHz and 100kHz
- All spikes are lightning signature (amplitude is linked to the strength of the source. A same lighting can be detected several times after several rotation around the Earth !)



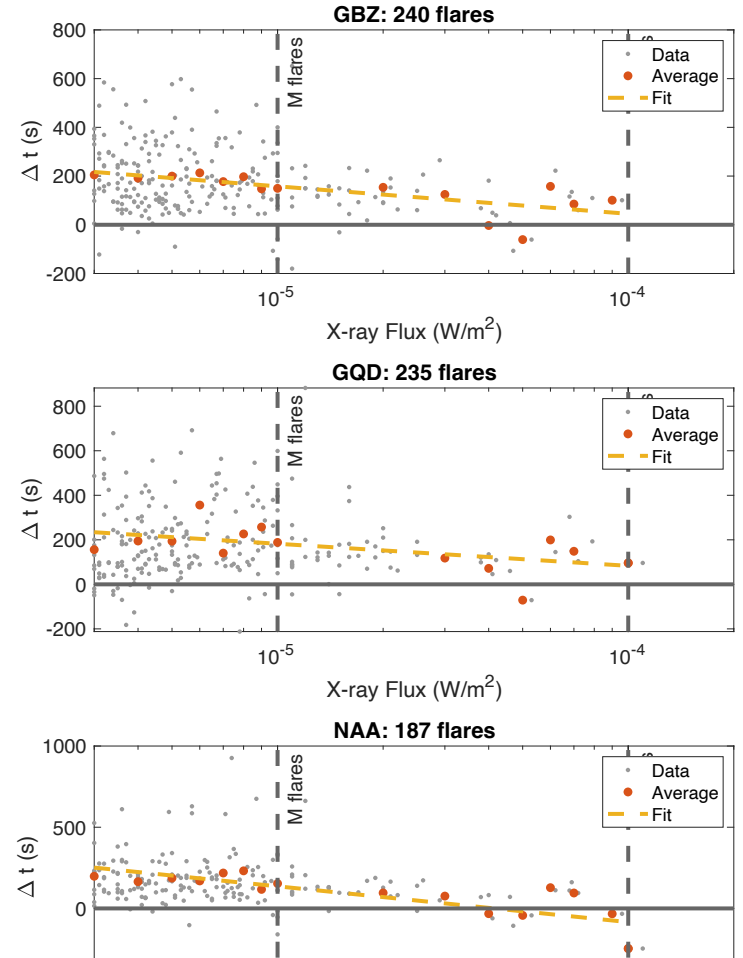
Sprite signature from Narrowband



NARROWBAND ANALYSIS: SOME EXAMPLES



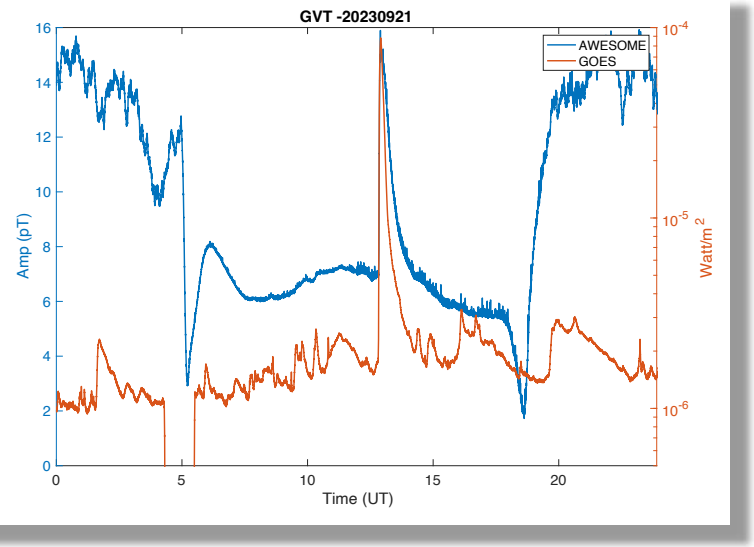
Time delay between Peak time in VLF and X
→ Time Response of the D-layer to a forcing



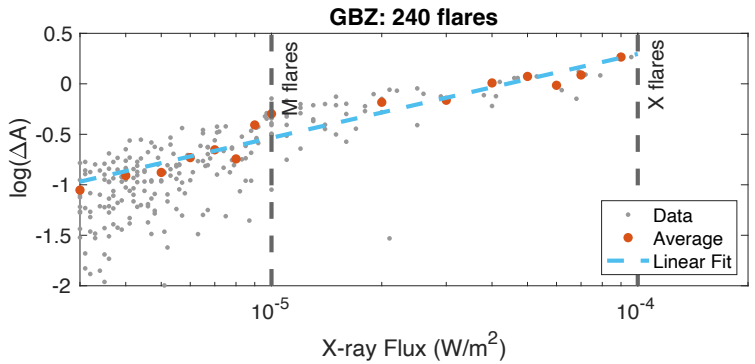
From UK (NS)

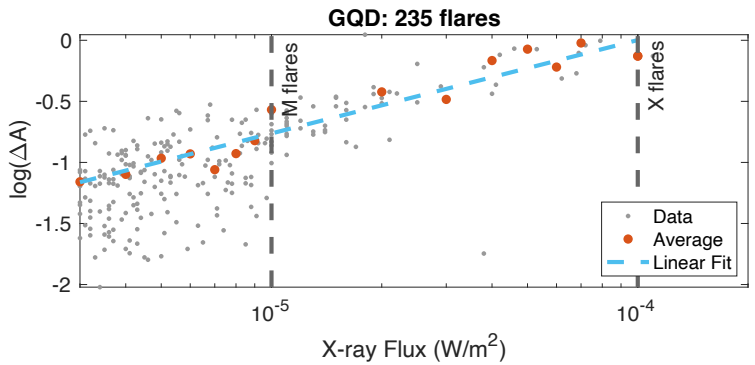
From USA (EW)

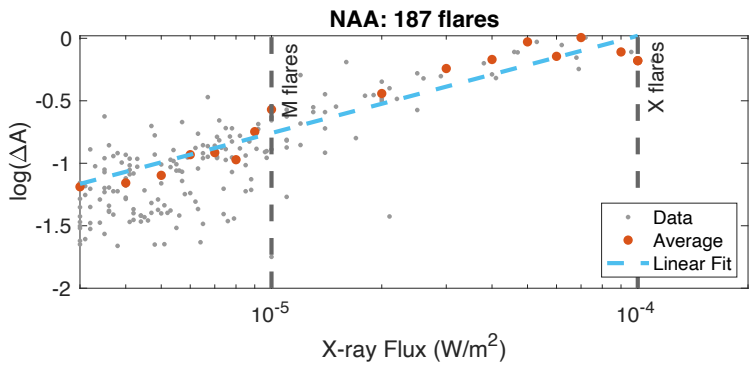
NARROWBAND ANALYSIS: SOME EXAMPLES



Amplitude in VLF vs. Flare strength →
Linear response of the ionosphere ?

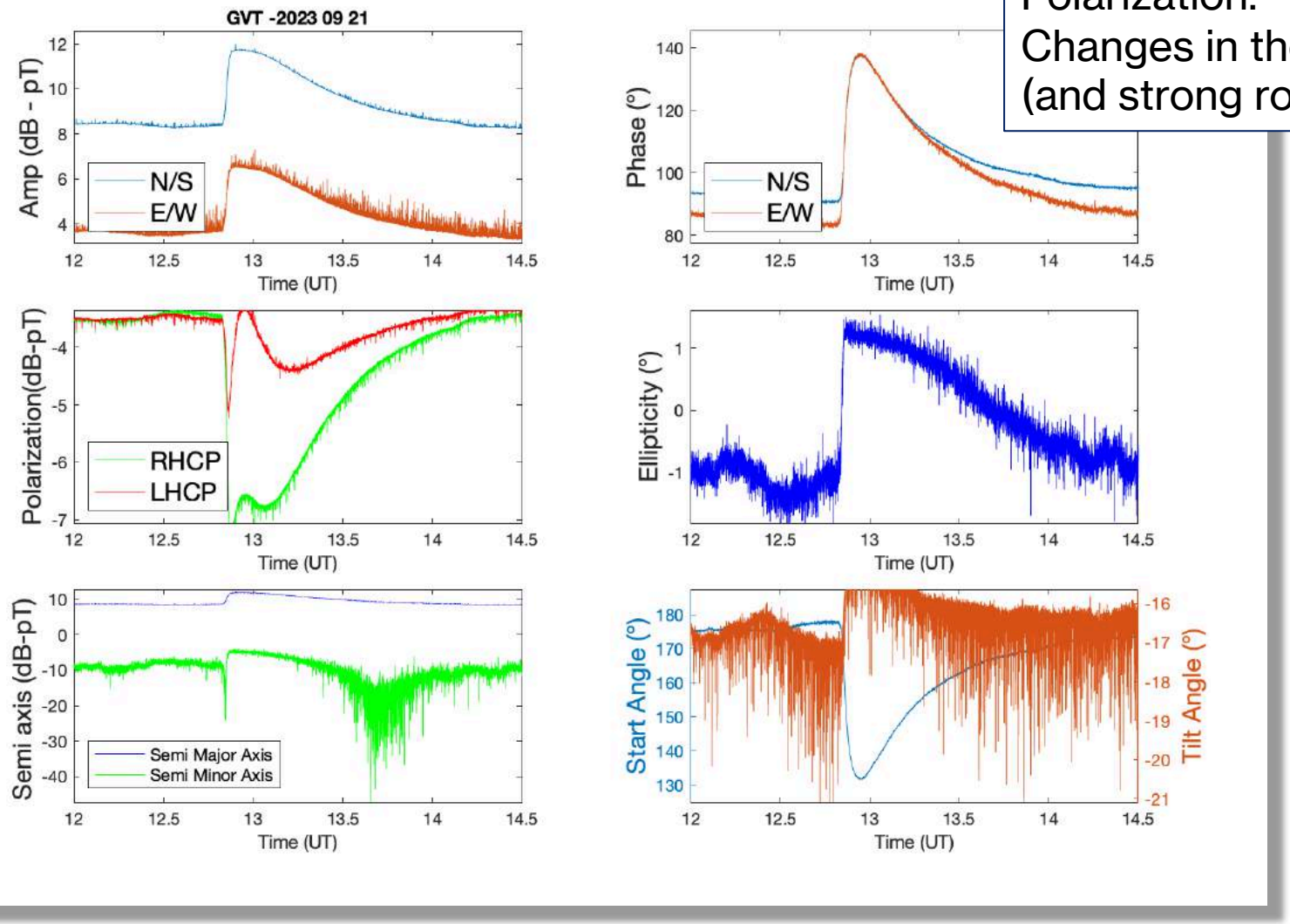






Missed strong flares (many occurred during night at Nançay)

NARROWBAND ANALYSIS: SOME EXAMPLES

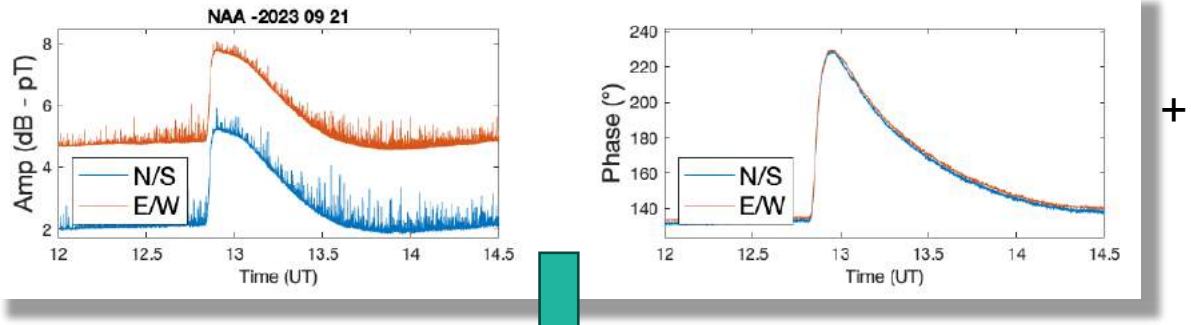


Polarization:
Changes in the wave phase. Different for each flare (and strong rotation for lightning related events)

MODELING

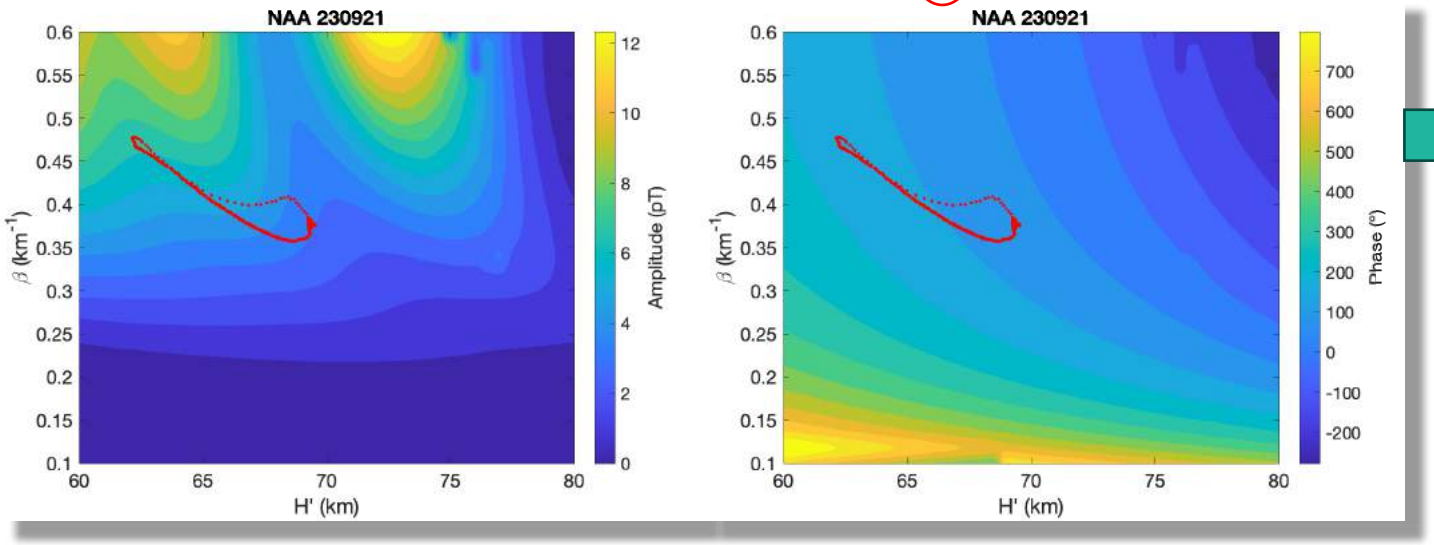
LMP propagation code (Gasdia & Marshall, 2021)

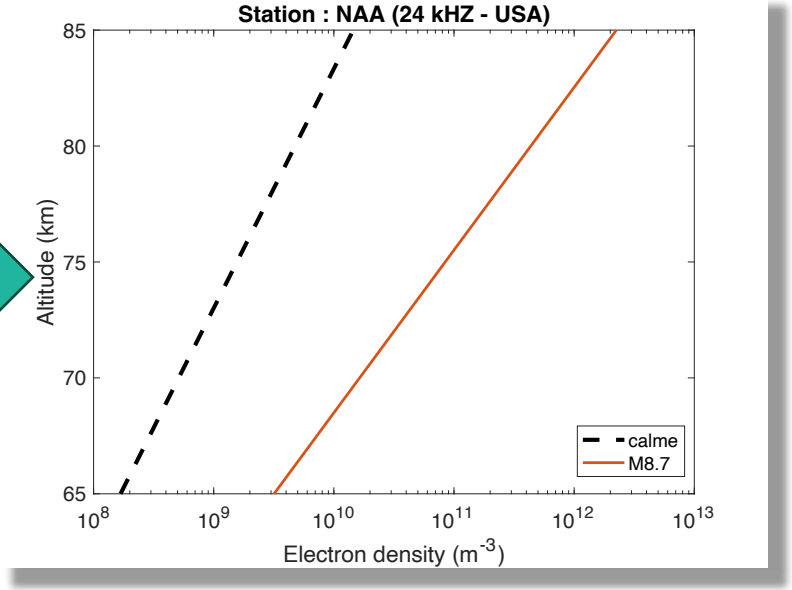
Inputs: Observations



+ path description (conductivity)

$$N_e(H', \beta, Z) = 1.43 \times 10^{13} \times \exp(-0.15 \times H') \times \exp[(\beta - 0.15) \times (Z - H')]$$



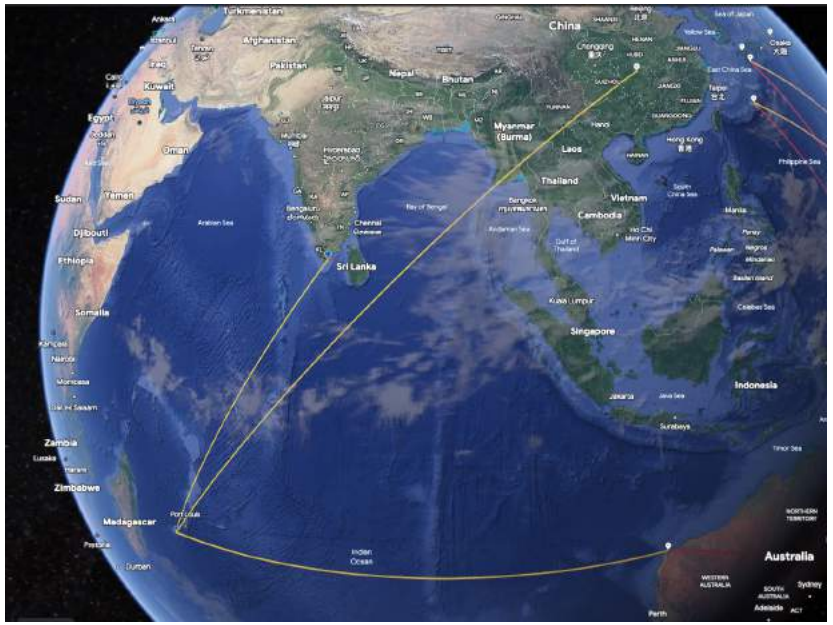


As the flare progresses, H' decreases and β increases

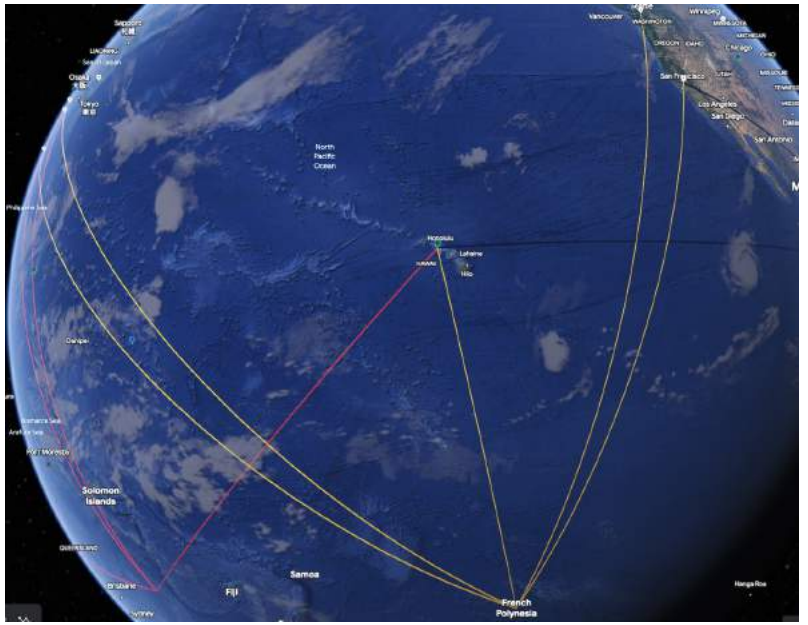
VNET4IONS: VLF NETwork for IONospheric Studies

Missing many flares (occurring during night at Nançay)

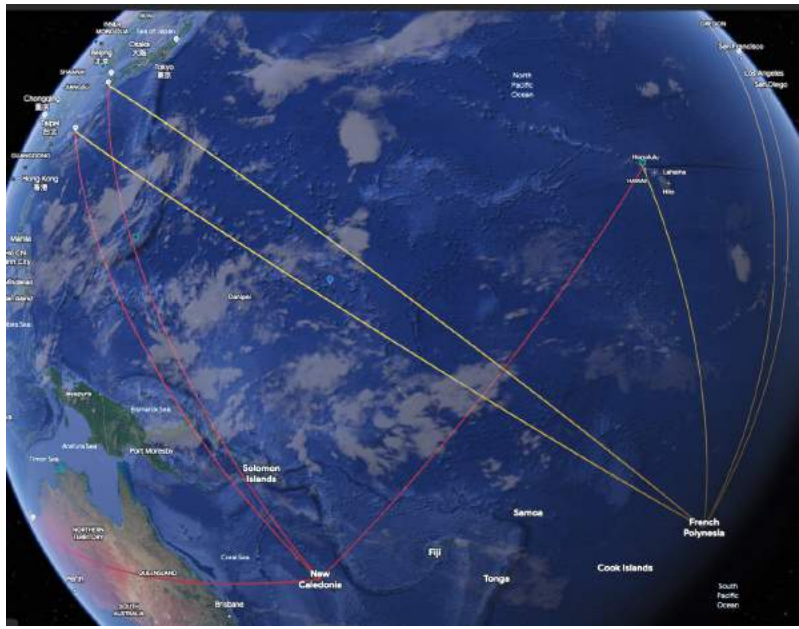
24h full coverage with a worldwide network on AWESOME instrument



La Réunion
Survey over Indian Ocean
Time Zone : [+4,+8]h

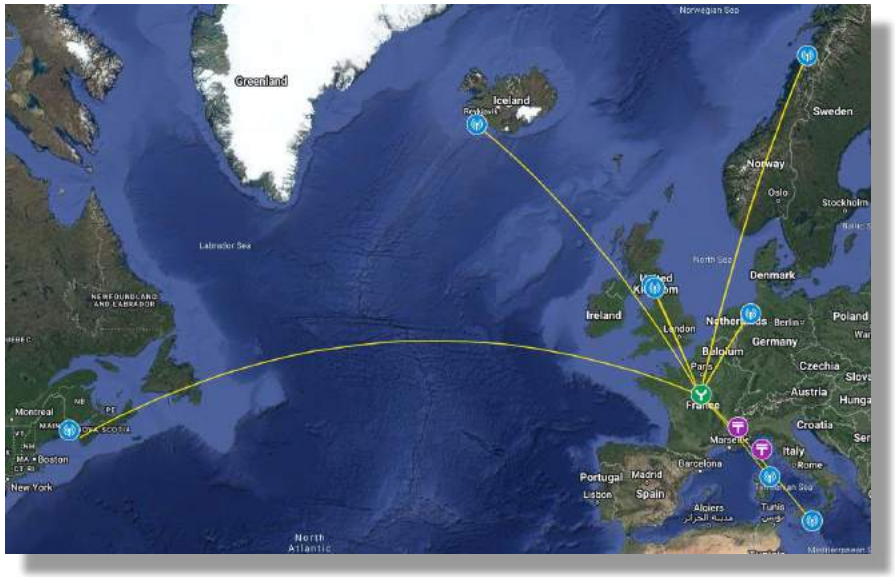


Polynesia
Survey of Pacific Ocean
Time Zone : [+8, -6]h



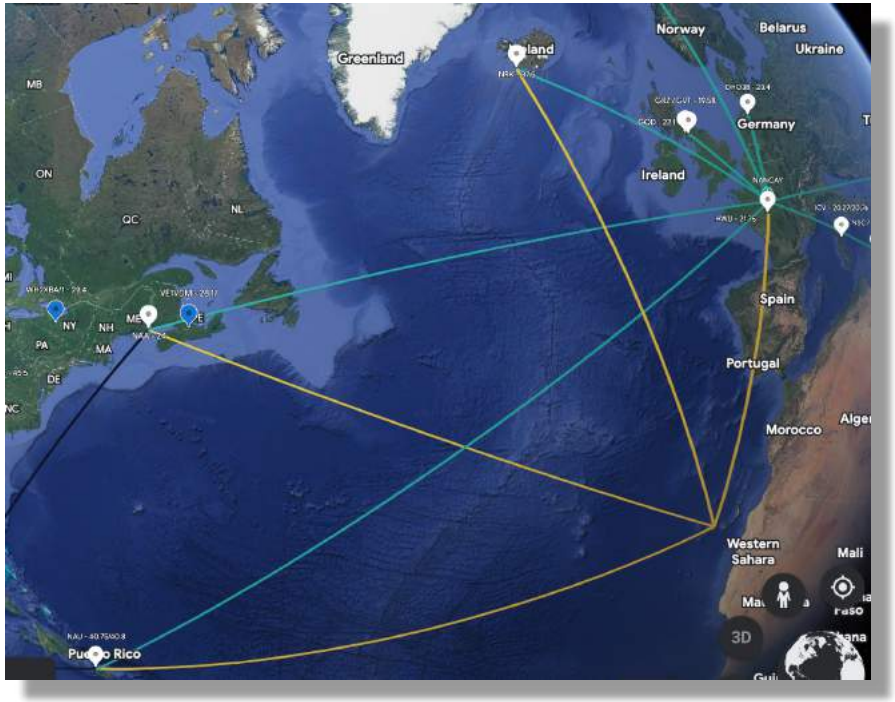
New Caledonia
Survey of Pacific Ocean
Time Zone : [+8, +12]h

North Atlantic coverage



Reinforced by an instrument in TENERIFE

- Studies on the spatial extension and propagation of the disturbances



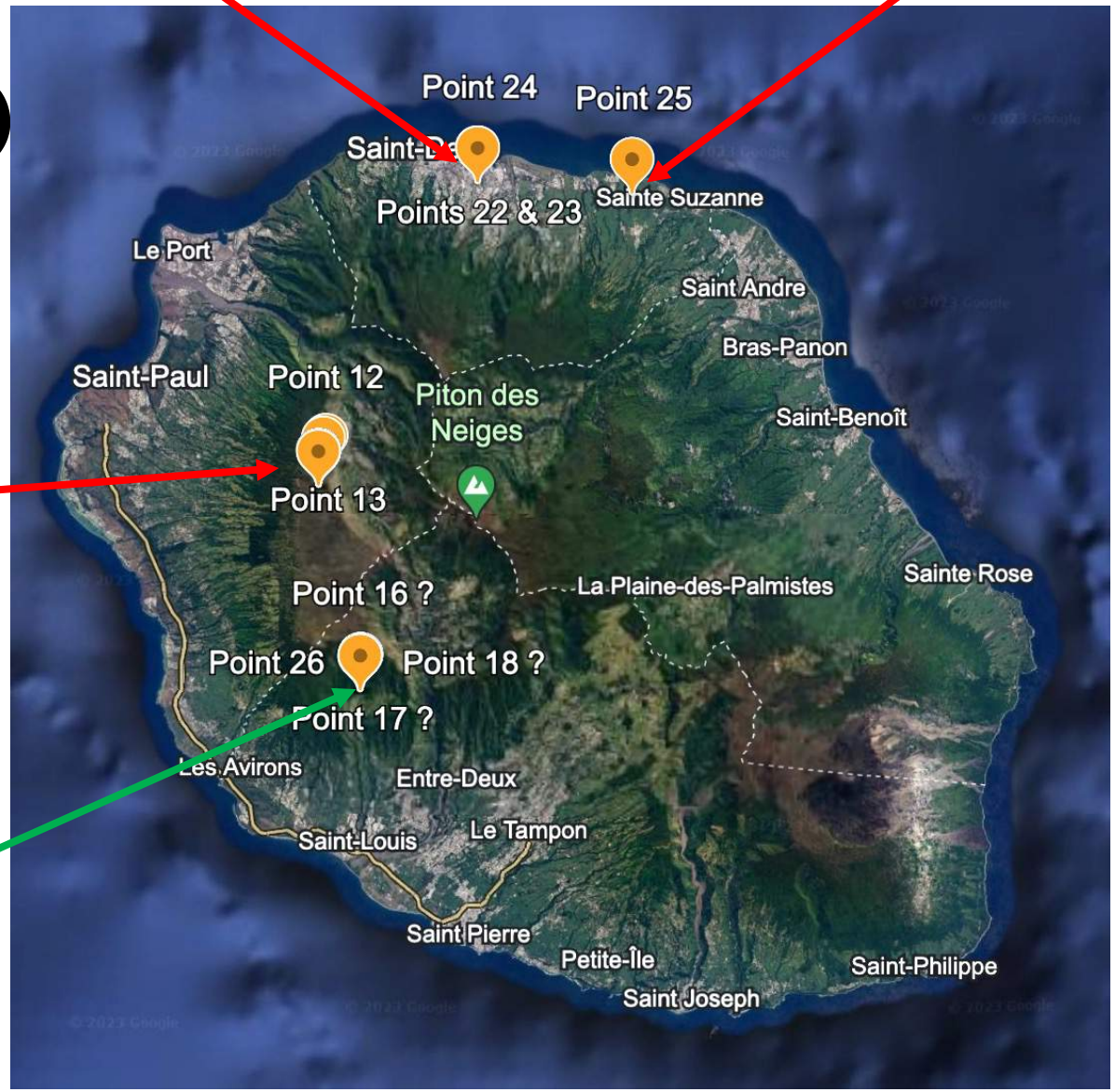
SITE TESTING IN LA REUNION (OCT. 2023)

Univ. Saint Denis

Military Base

Maido: professional atmospheric observatory (INSU) + Viewpoint in the national Park of Mafate

Les Makes: amateur astronomical observatory



Home message + prospective

- **VLF4IONS :** a project to study the perturbation of the ionosphere from two main sources: the sun & storm areas
- **Scientific & societal objectives**
- Require the development of **a network of VLF receivers around equatorial regions**
  - Support requested to CSAA
- Data processing codes: main steps OK
- Modeling:
  - VLF propagation OK
  - Ionospheric chemistry instead of (H',β)

- Implement AWESOME in La Réunion: **April 2024** (after the cyclone period) → antenna funded by PLAS@PAR (ready in the US)
- March 2024: Prospection in Tenerife (taking advantage of an URSI colloquium in Gran Canarias)
- 2024: Contact the Observatory of Tahiti (INSU), first trip in 2025
- Real-time analysis: Require the development of on-site data processing