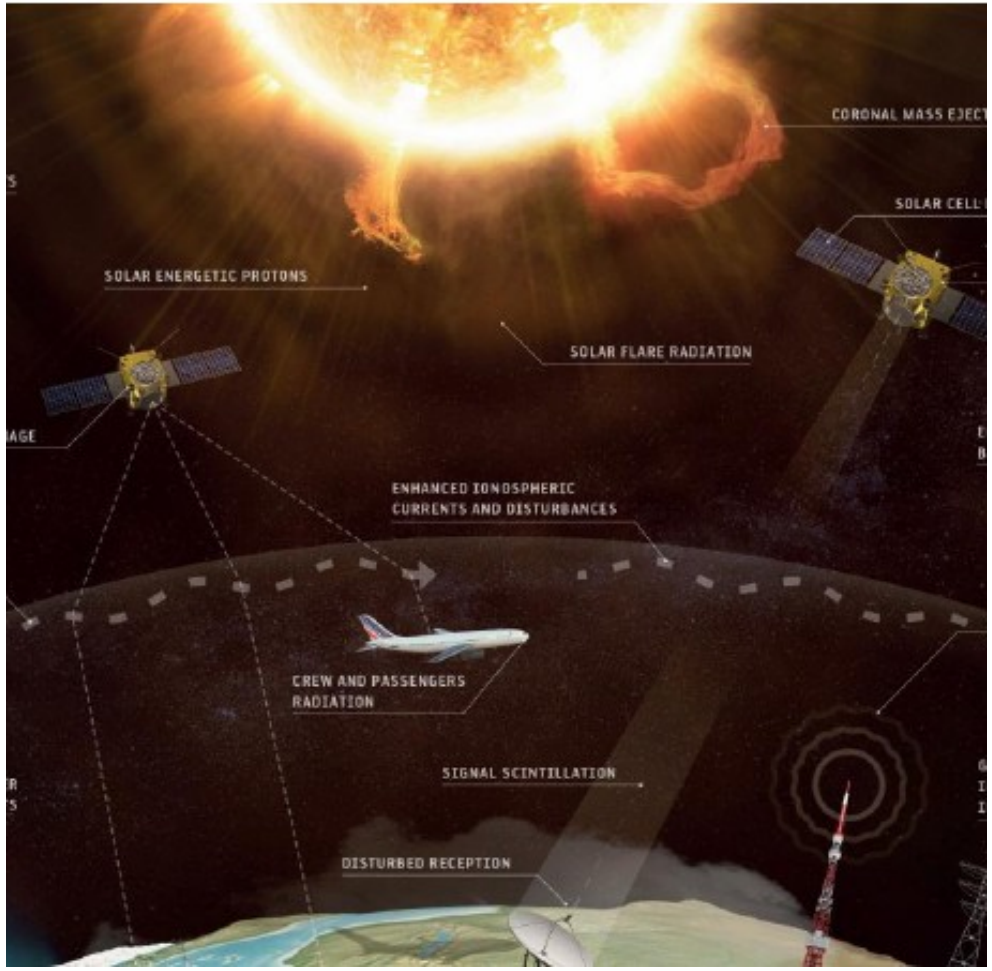
DISPEC TRAINING SCHOOL

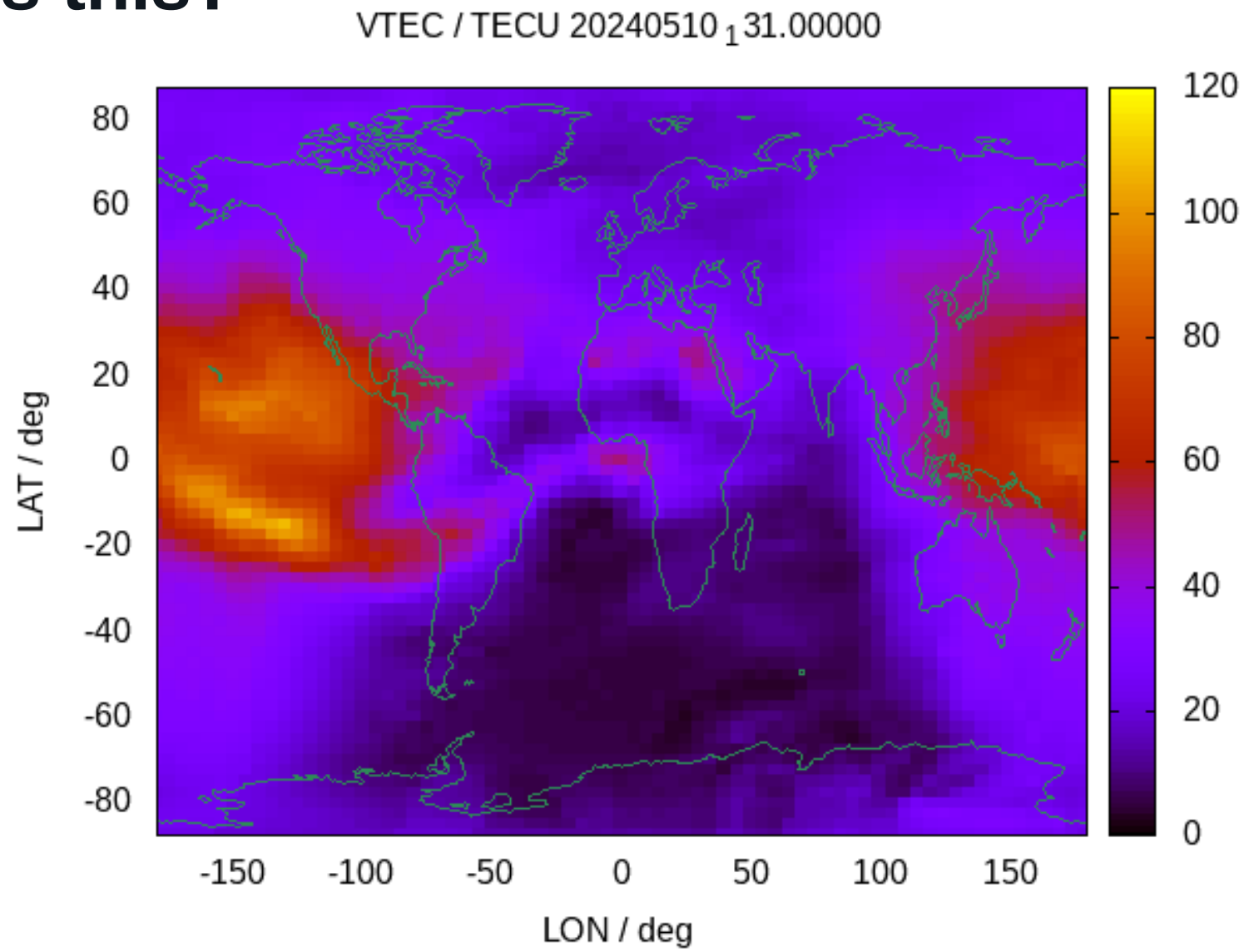
Ionospheric disturbances and irregularities

Anna Belehaki (1) and Manuel Hernandez-Pajares (2)
(1) Ionospheric Group, IAASARS, National Observatory of Athens, Greece
(2) UPC-IonSAT Research Group, IGS Associate Analysis Center, Spain



Several motivating questions...

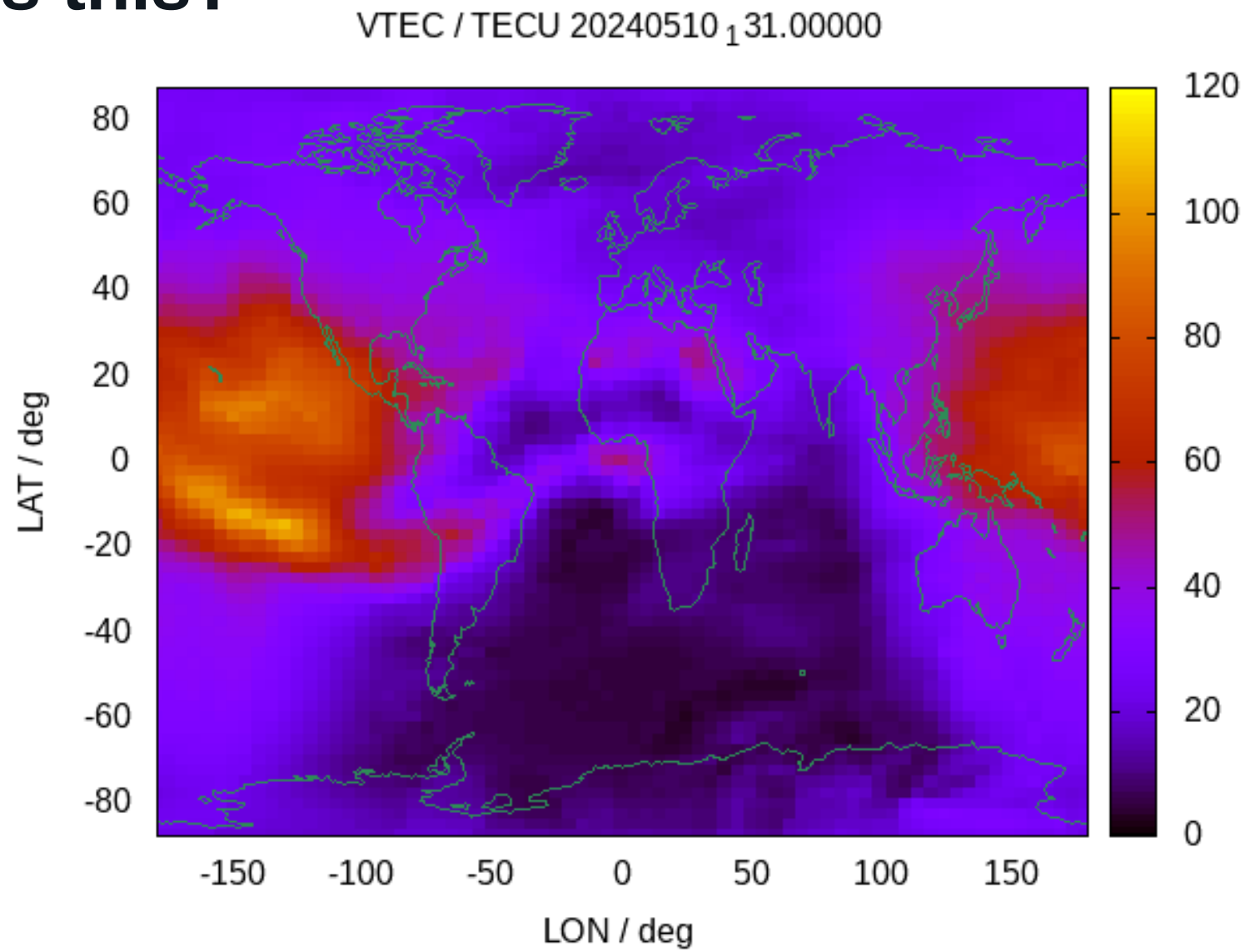
Question #1: What is this?



Question #1: What is this?

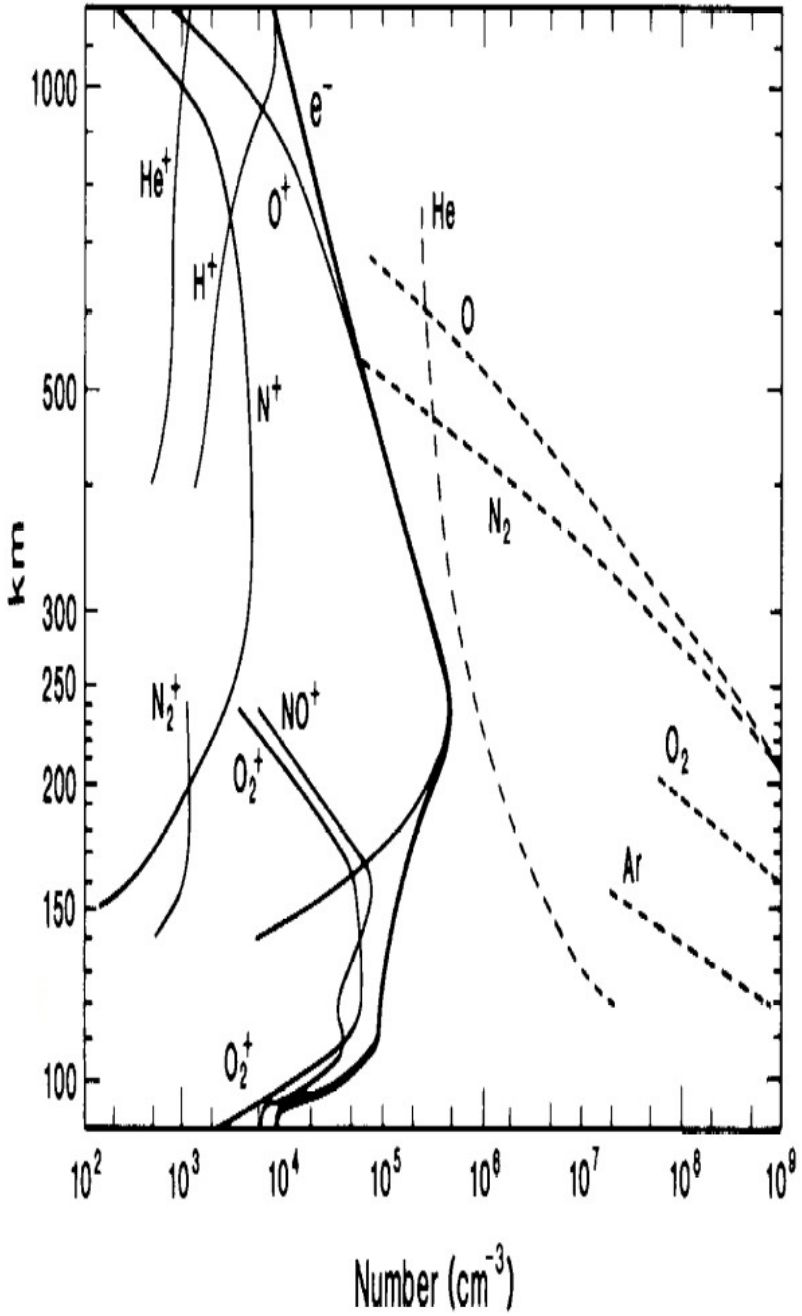
Movie of the vertically integrated electron number density (AKA Vertical Total Electron Content, VTEC) of the partially ionized part of the Earth atmosphere (ionosphere) obtained from worldwide Global Navigation Satellite System (GNSS) multifrequency measurements (10 May, day 131, of 2024, starting at the end a huge ionospheric storm)

Do you wish to check the present global VTEC, from RT UPC-IonSAT GIMs? If yes:



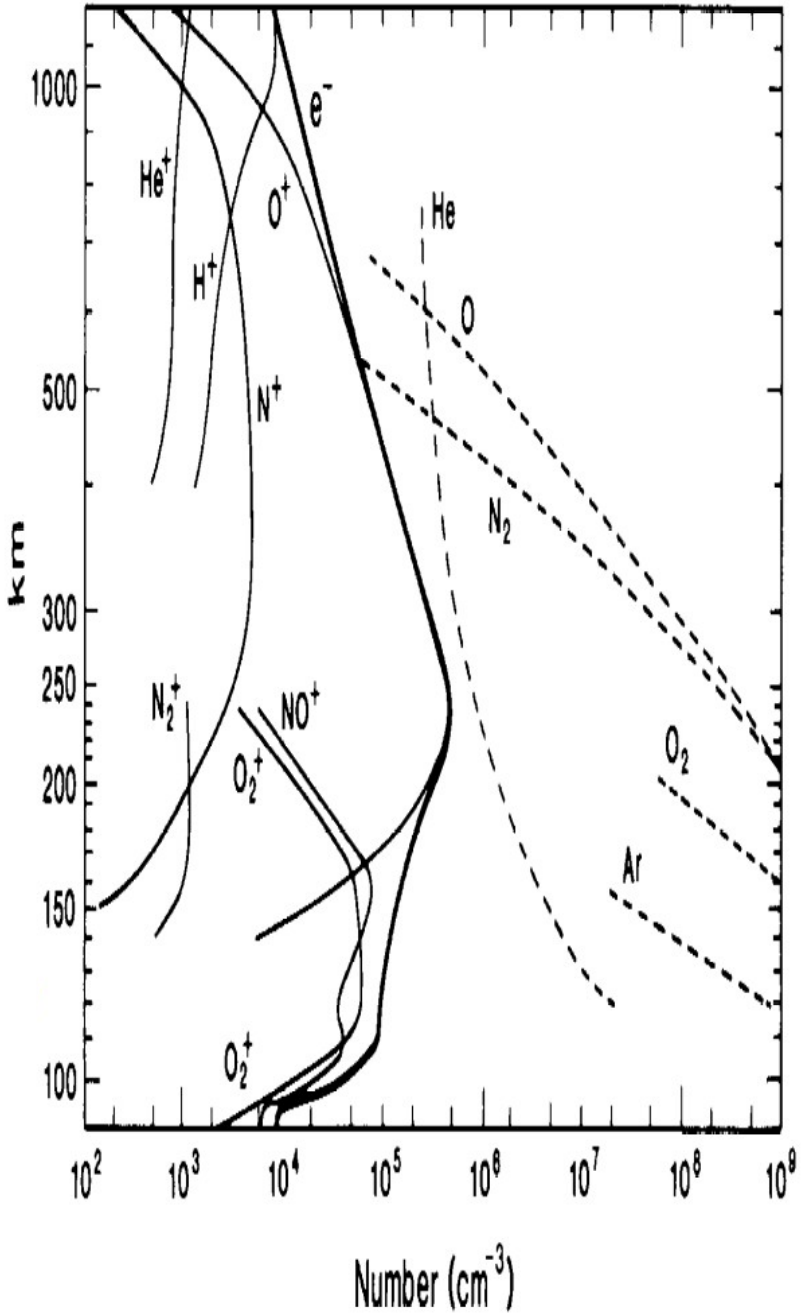
http://chapman.upc.es/tomion/real-time/quick/last_results.uadg/RT-DAILY-VTEC-MOVIE.gif

Question #2: Why are there free electron within the Earth atmosphere?

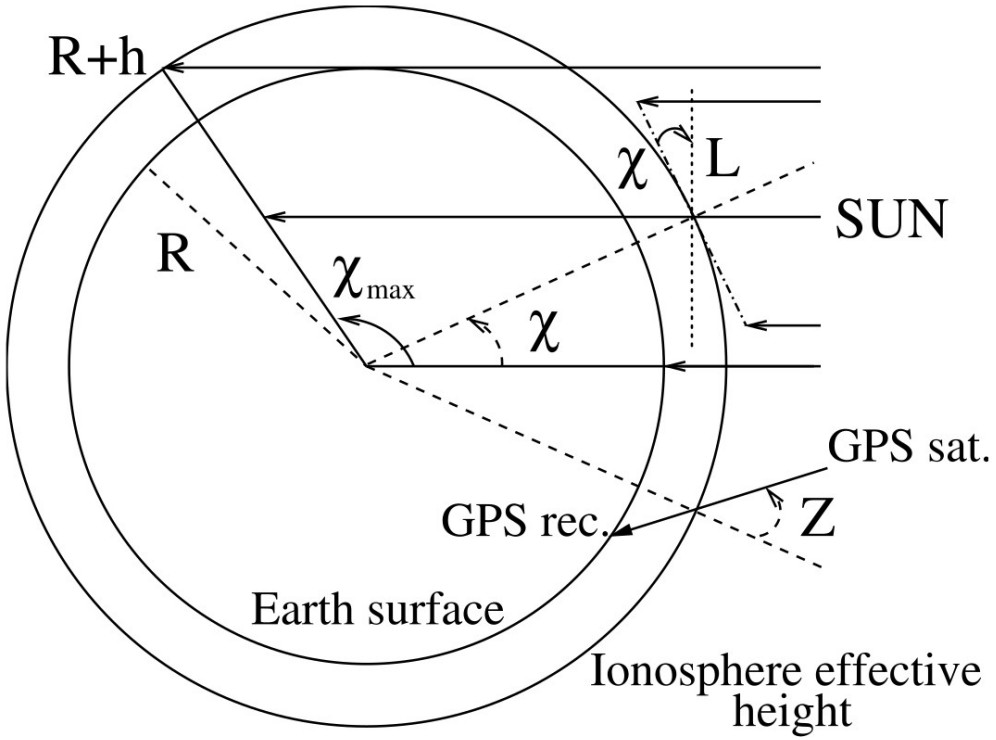


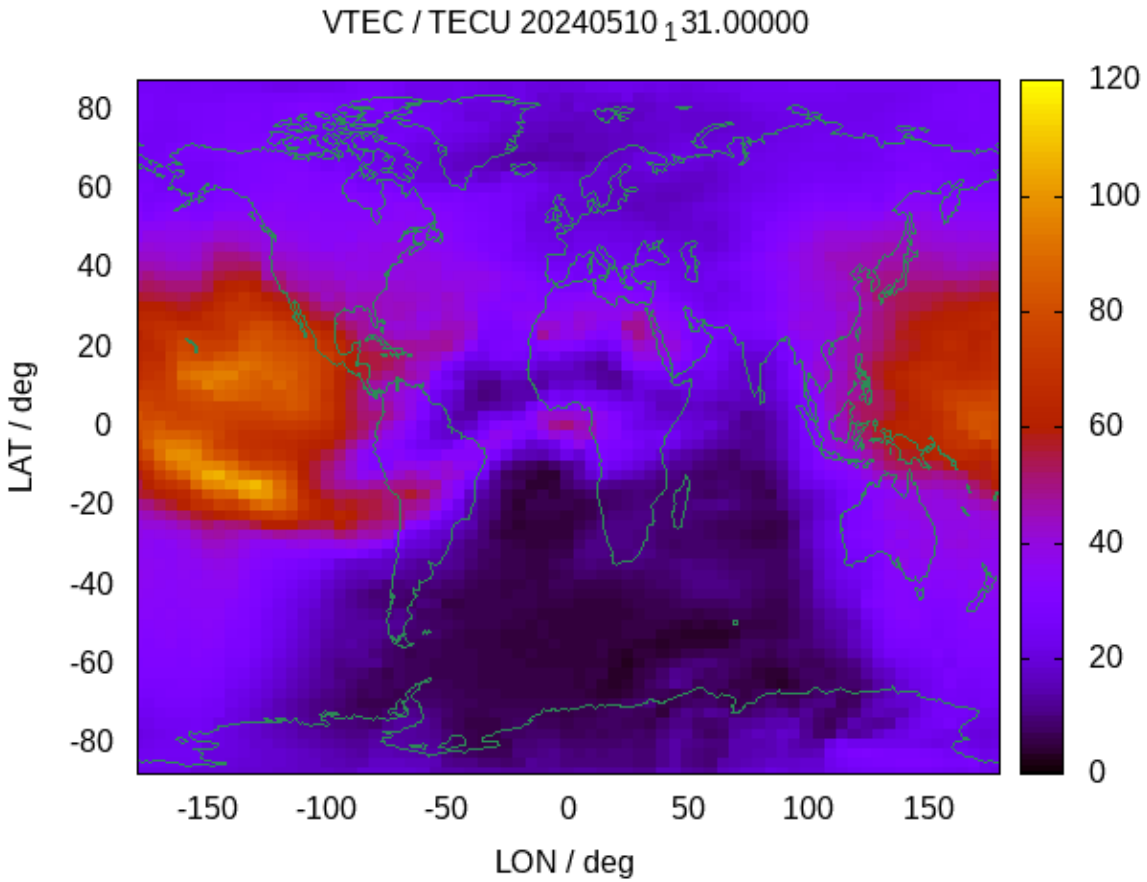
Question #2: Why are there free electron within the Earth atmosphere?

The chemical reactions on the Earth atmosphere of dissociation of different molecules at different heights by solar photons (mostly in EUV and X-ray bands) generate the free electrons.



Question #3: How can the VTEC distribution be explained?





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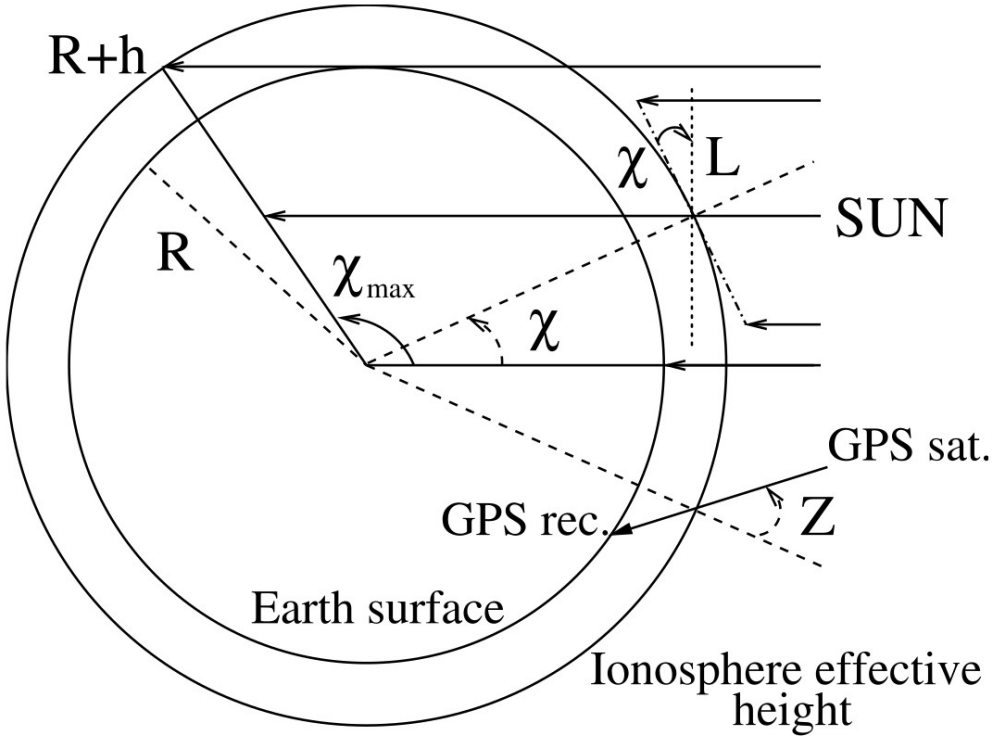
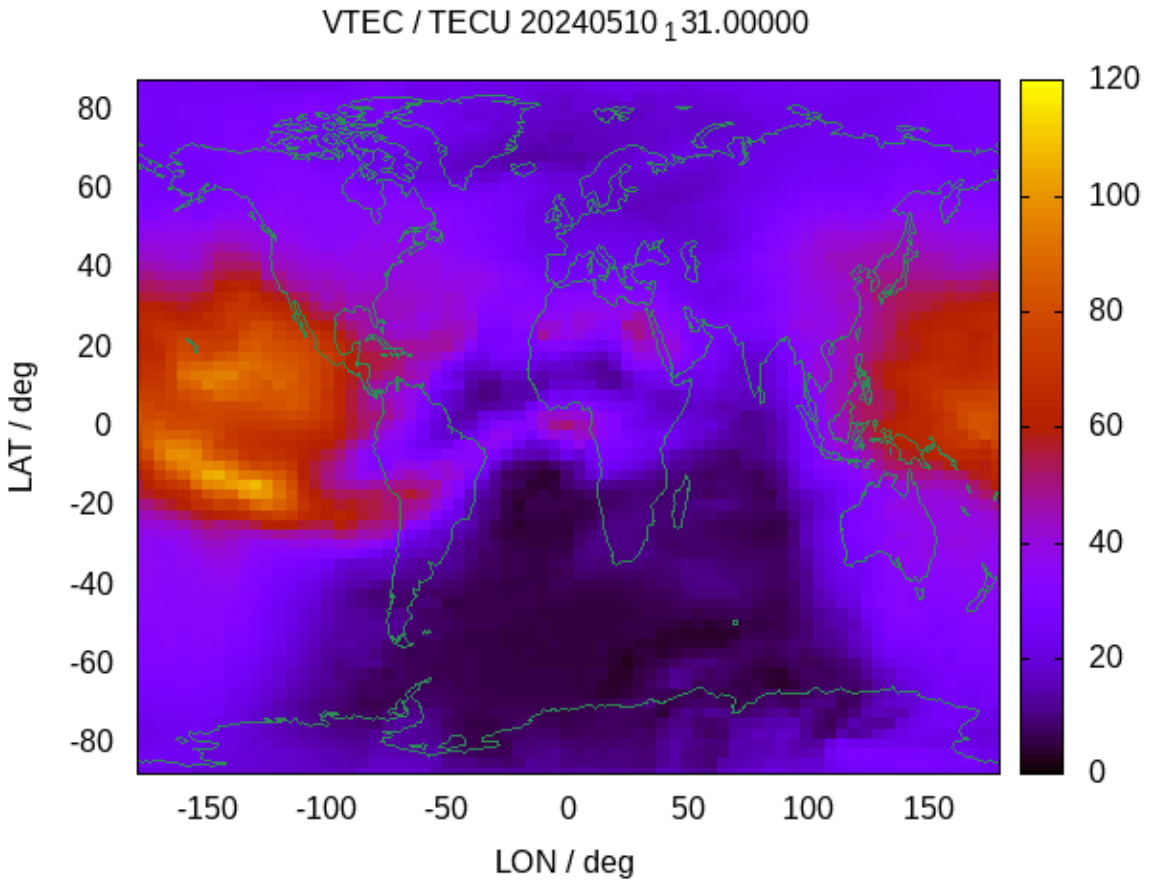
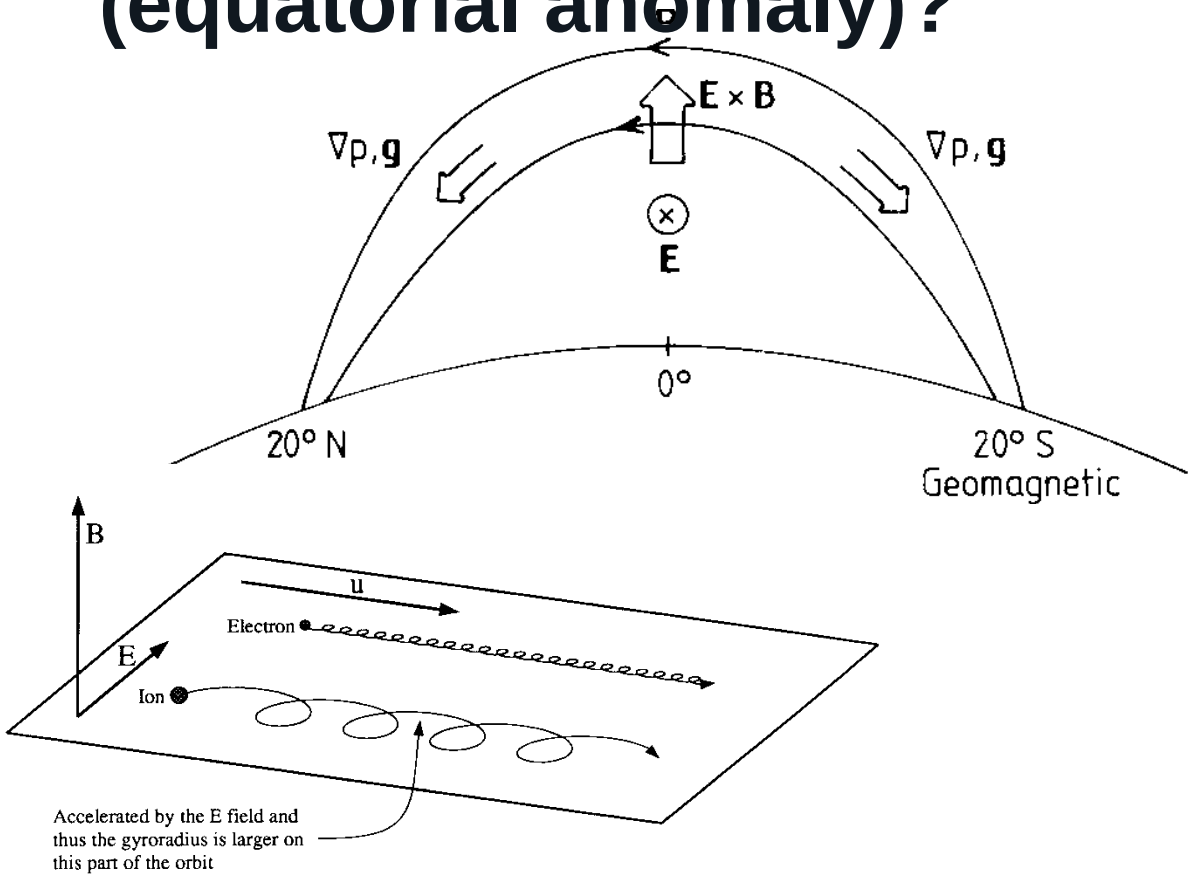


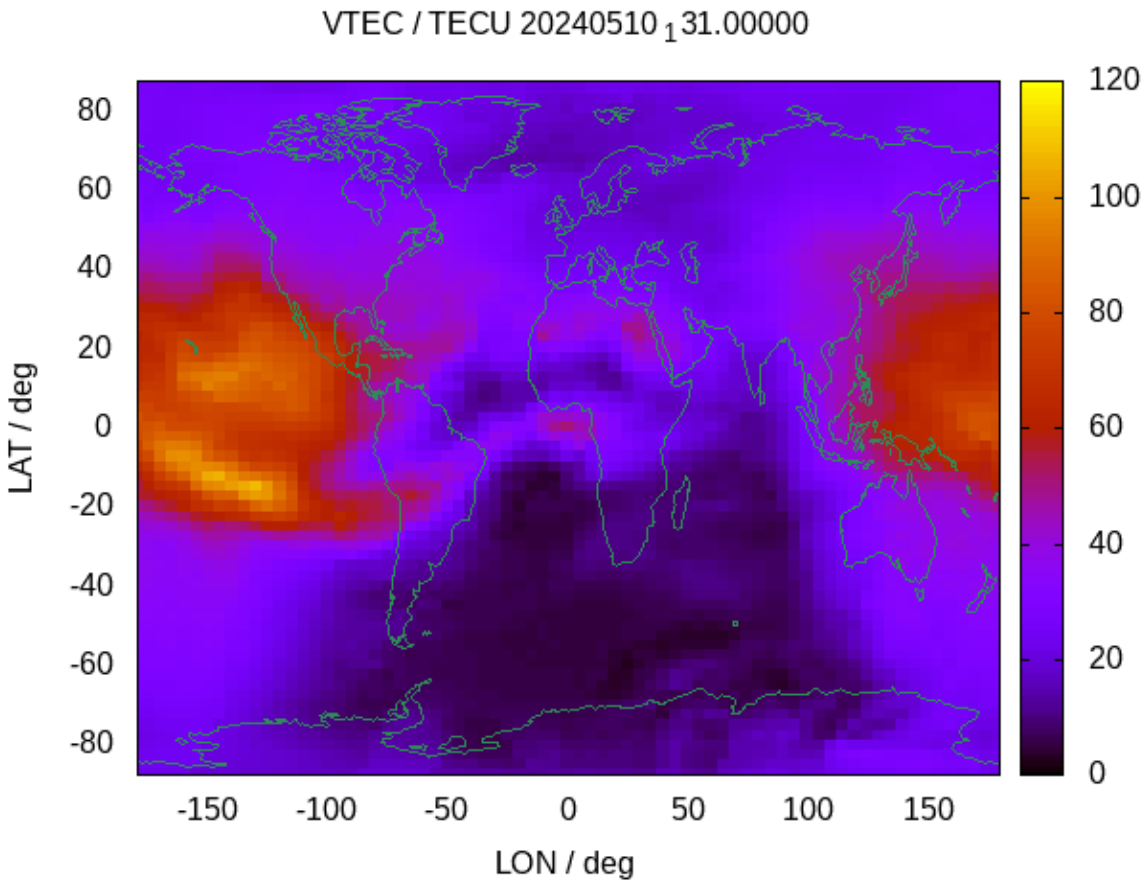


- In normal, geomag. quiet conditions (e.g. first half for this day, May 10th 2024, right before the May 2024 superstorm starting) a first main explanation: the different EUV and X-ray solar irradiance in function of the solar-zenith angle (I.e. in latitude and local time -see the Earth rotation ionospheric footprint!-)

- In unusual, geomagnetically active conditions (see last hours in VTEC movie), other mechanisms can strongly distort the distribution positively (VTEC excess) and/or negatively (VTEC reduction) -see below-.

Question #4: What about the double VTEC peak (equatorial anomaly)?





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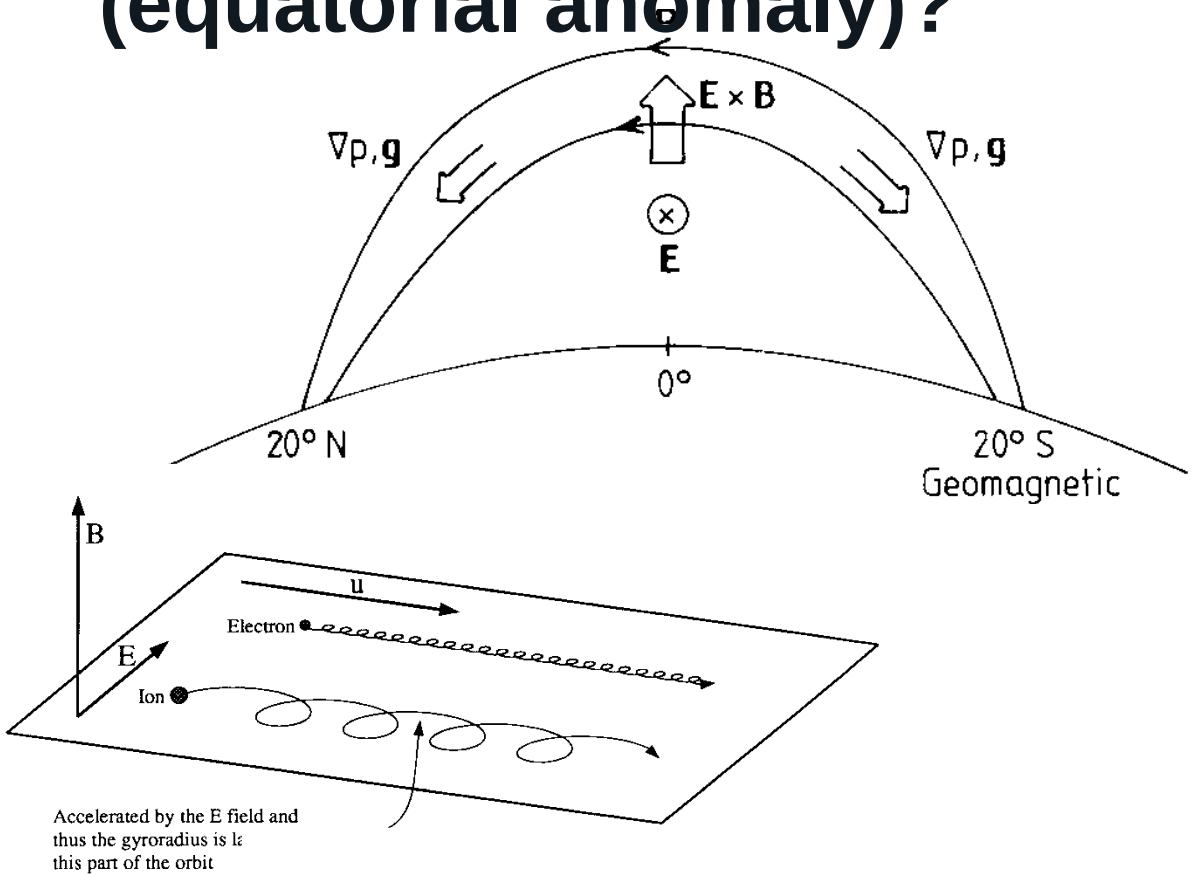
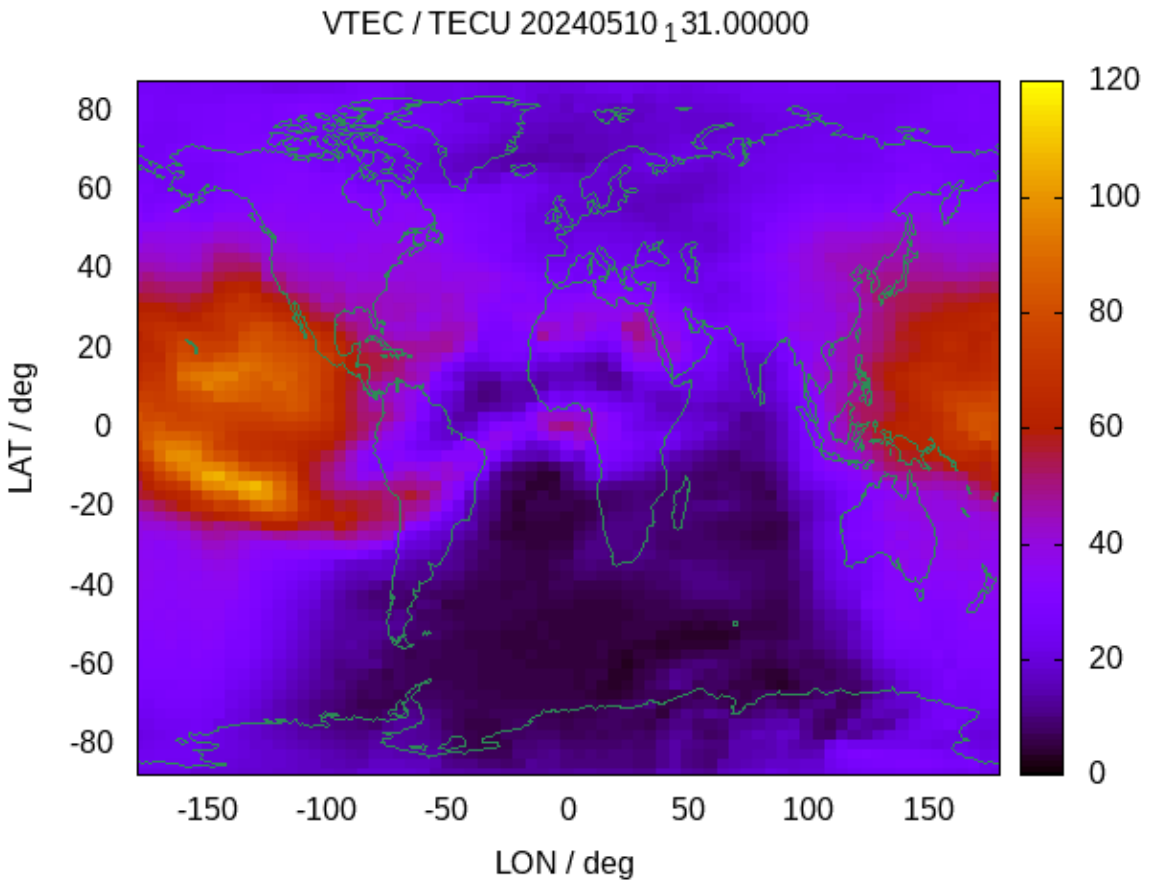
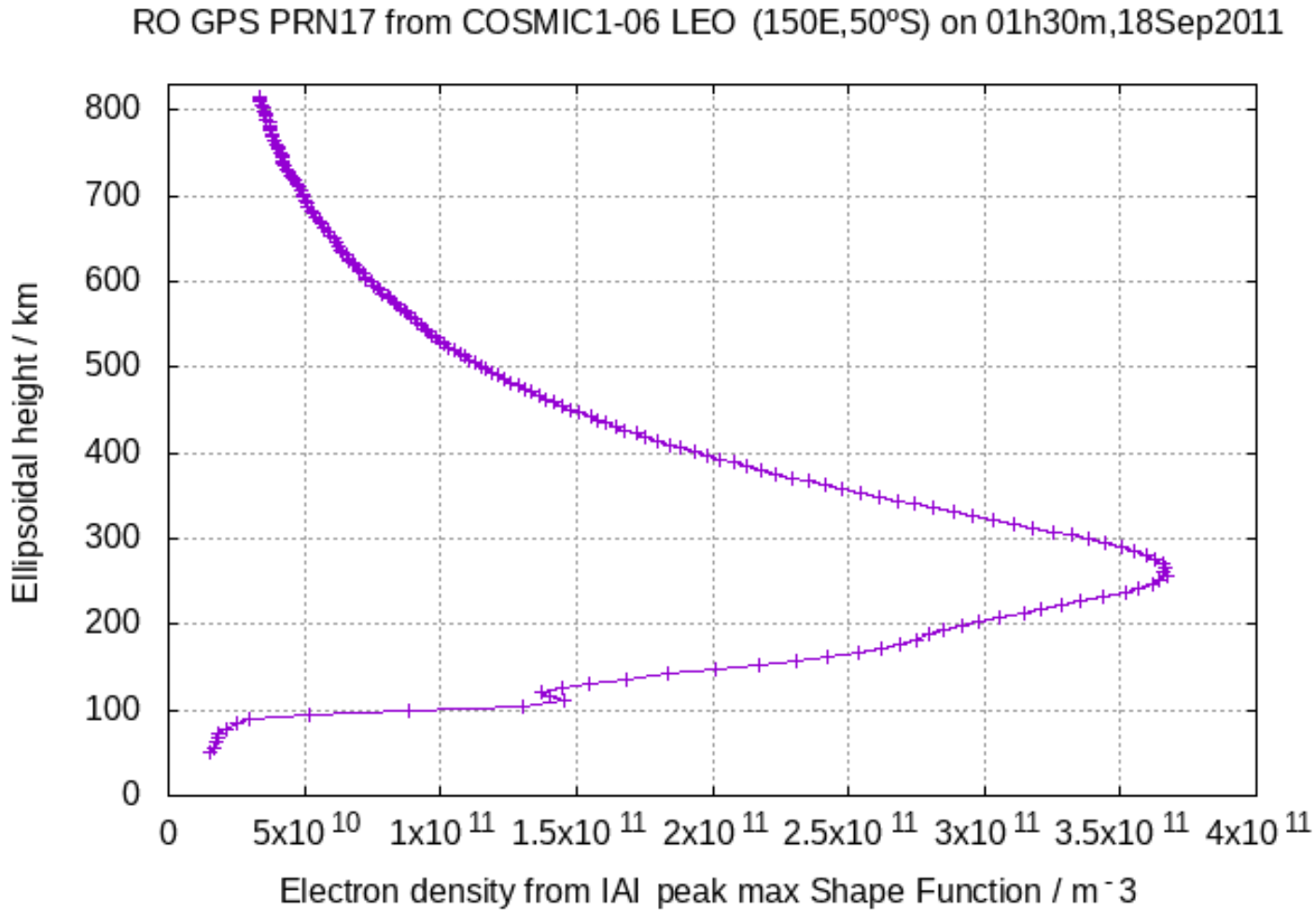




ExB drift, contributes to the fountain effect, and then, the equatorial anomaly and double peak, with a central role of the magnetic field, the magnetic equator in particular, in the distribution of the free electrons of the Earth ionosphere.

Question #5: How can the vertical distribution of free electrons be explained?

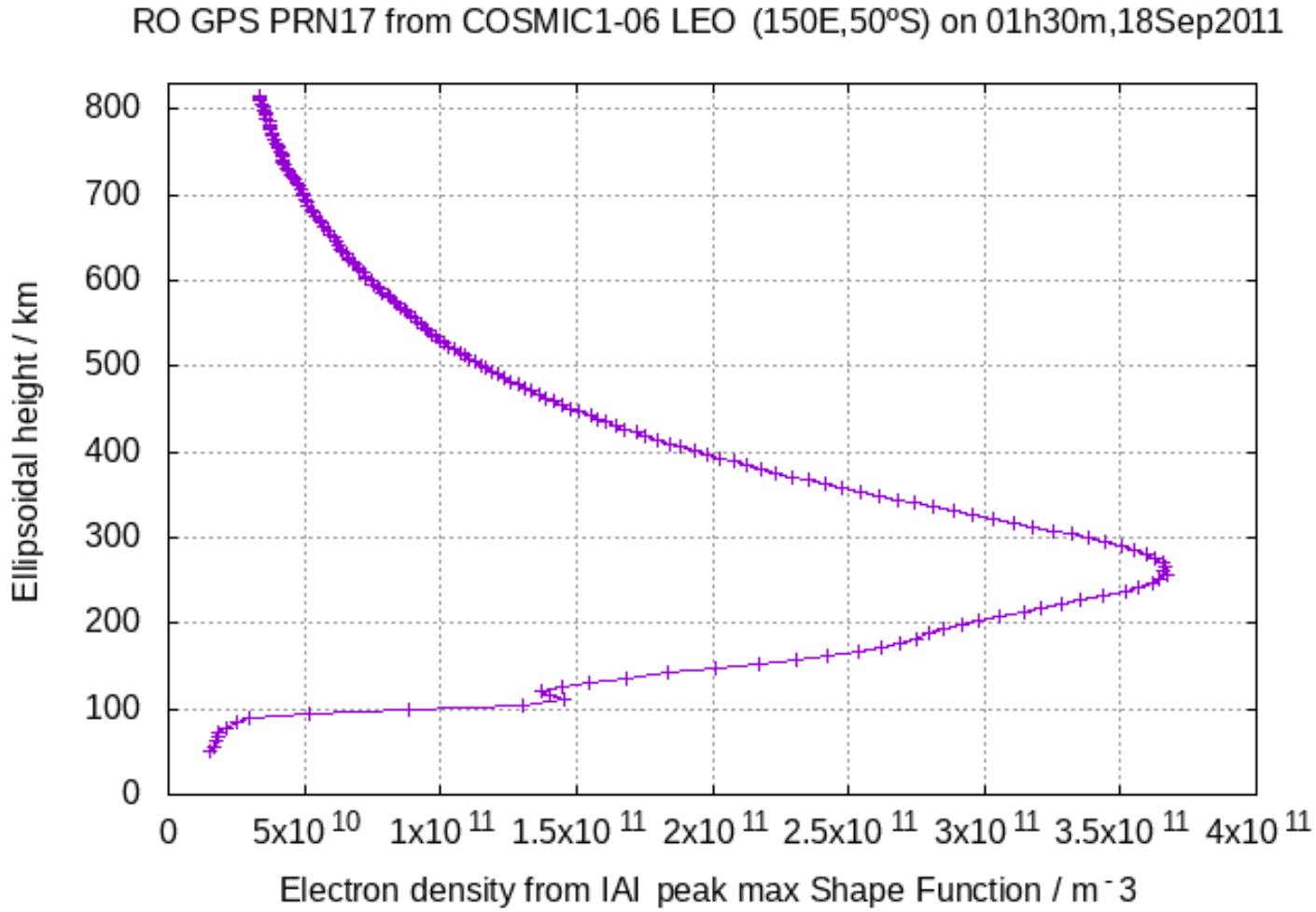


Question #5: How can the vertical distribution of free electrons be explained?

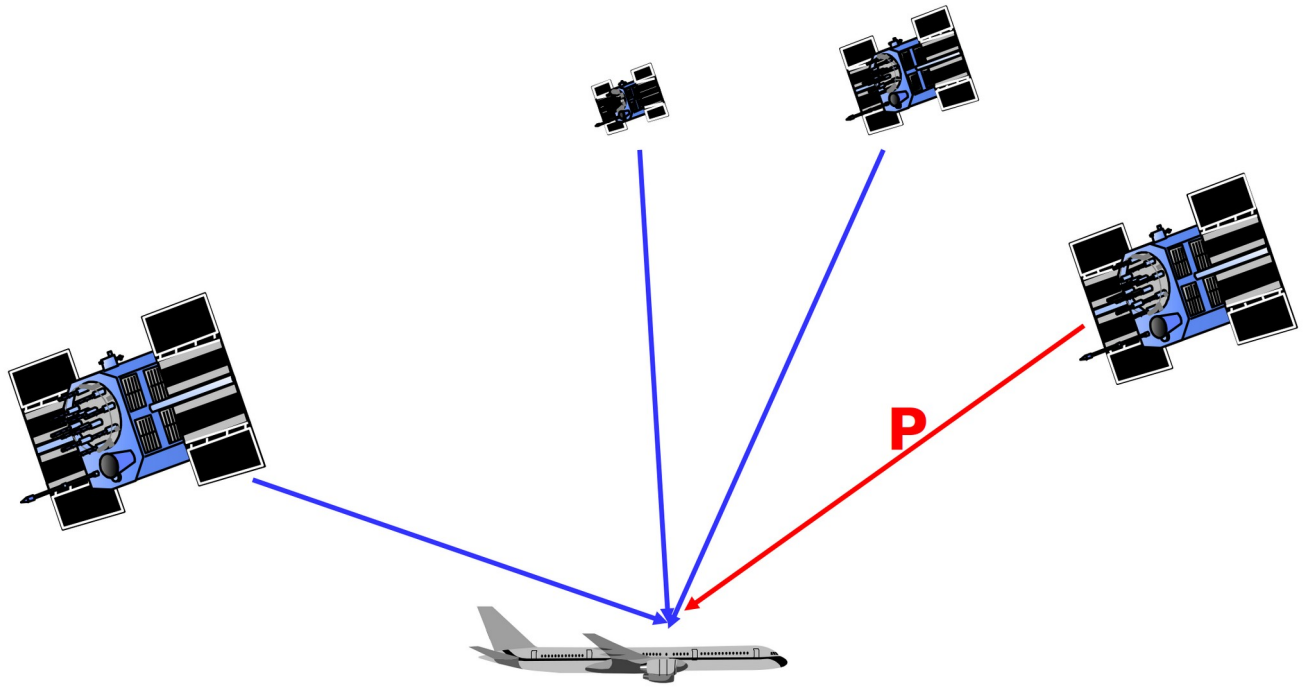
- The electron number density (hereinafter electron density) vs height(*).

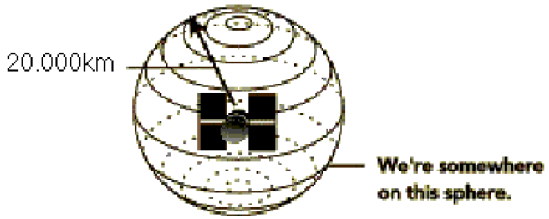
- The intermediate electron density peak height can be understood as the optimal height of production of free electrons, a compromise between enough number of target molecules and enough ionizing solar radiation, specially in EUV.

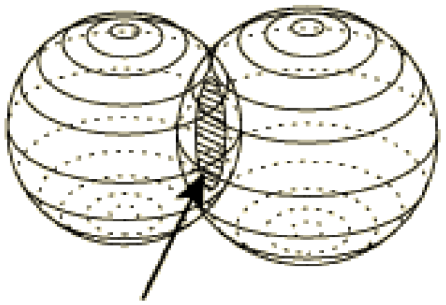
(*) Estimated thanks to GNSS receivers flying on a Low Earth Orbiting satellite -in this case FORMOSAT-3/COSMIC- measuring multifrequency GNSS signals from transmitters below the LEO local horizon (radio-occultation scenario).

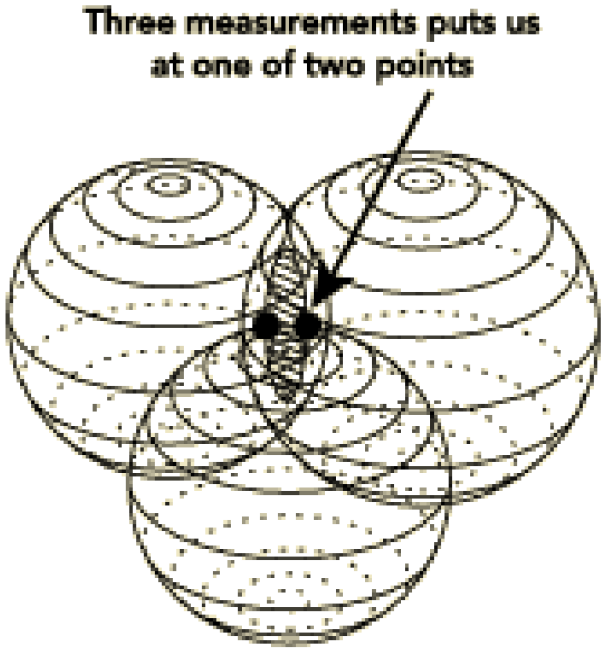


Question #6: And what about this? Any guess?









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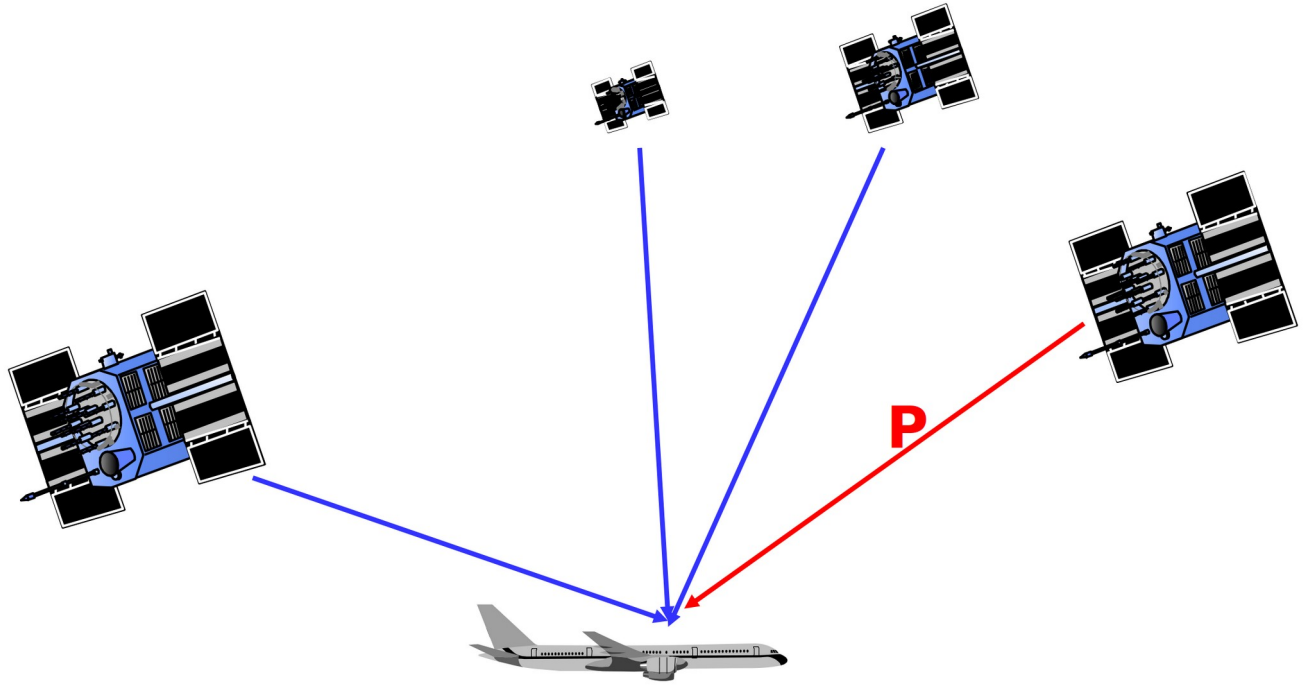
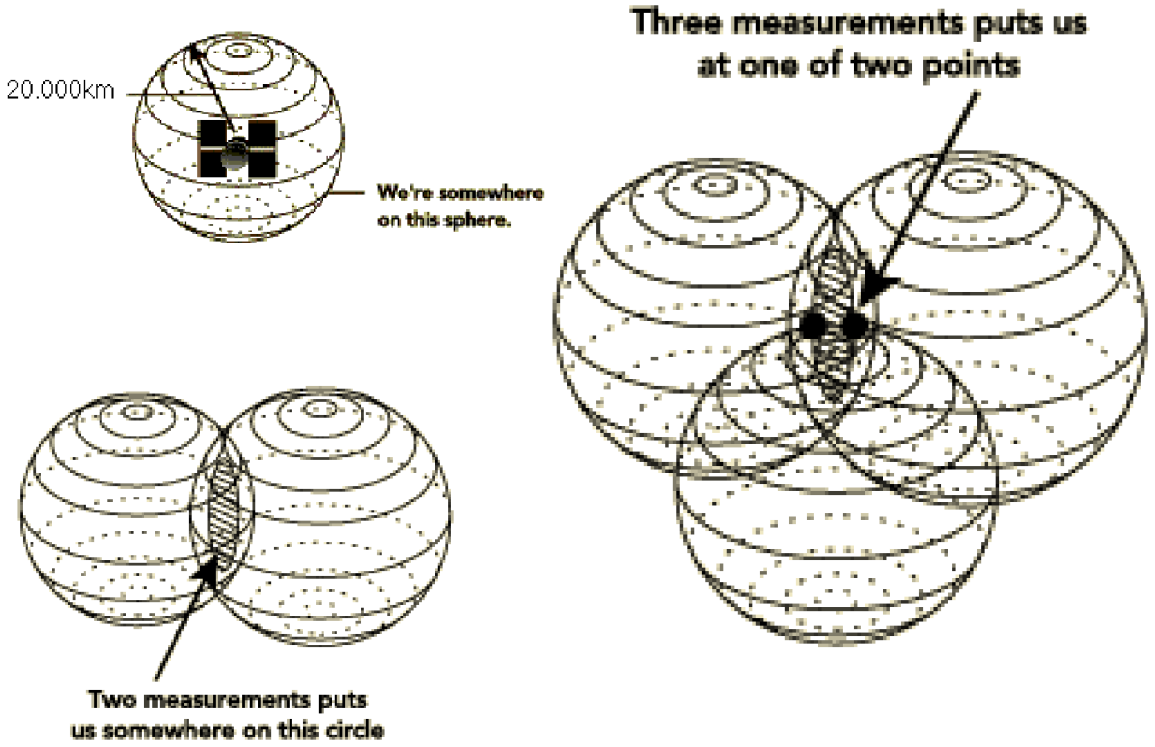


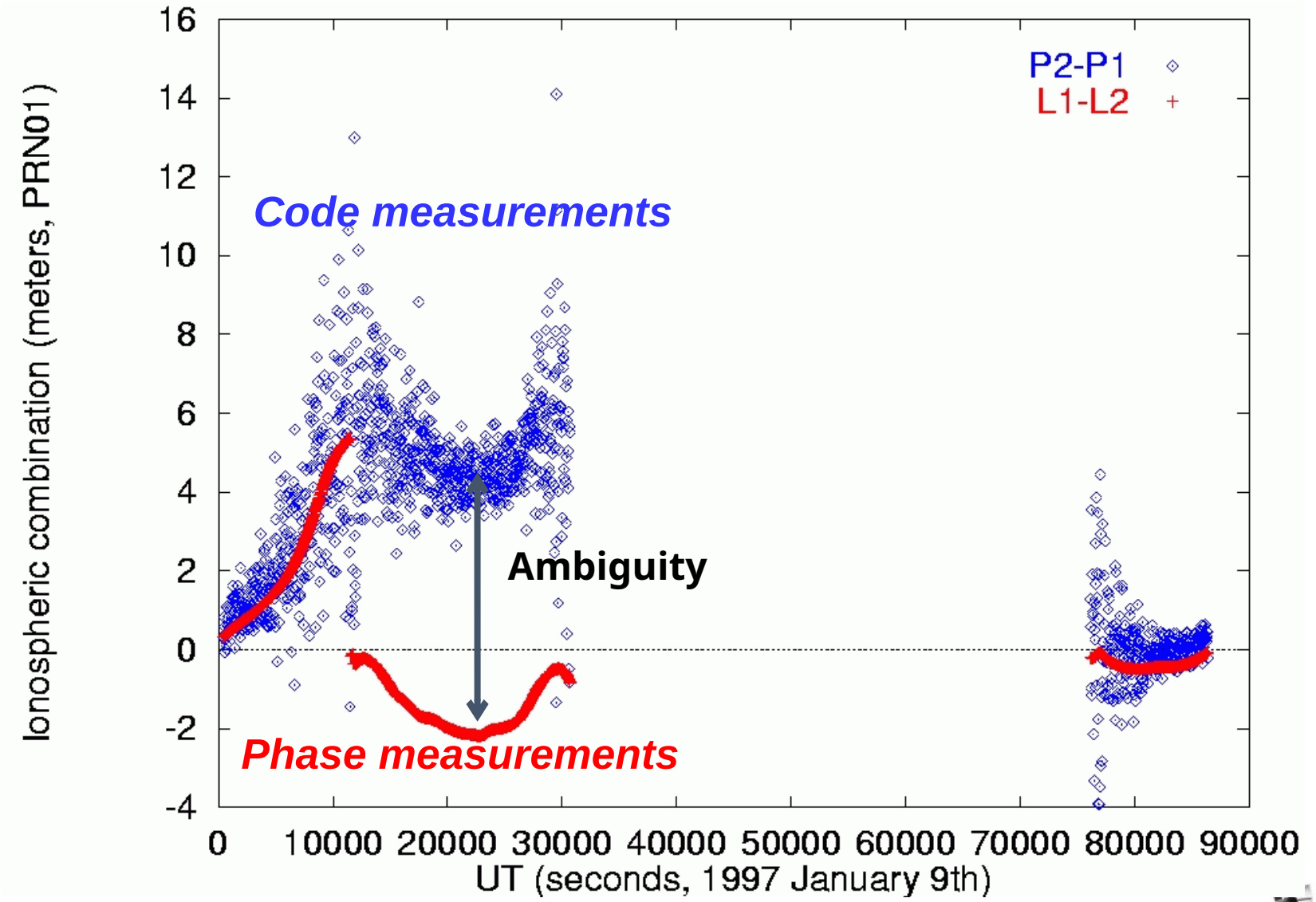


Left: These are four Global Positioning System (GPS) transmitters providing pseudorange signals (P) to a roving receiver, within the +100 transmitters available, belonging to the Global Navigation Satellite Systems (GNSS), GLONASS, Galileo and Beidou, among GPS (the distance scale is not real).

Right: It illustrates the trilateration concept, foundation of GNSS for positioning: knowing the position of the center of at least three(*) spheres in different directions -GNSS transmitters on MEOs- and the radius of such spheres -from the P obs.-, we “intersect” them to estimate the receiver position X,Y,Z).

(*) at least four satellites are needed taking into account the receiver clock error unknown

Question #7: Now, any guess or comment about this plot?

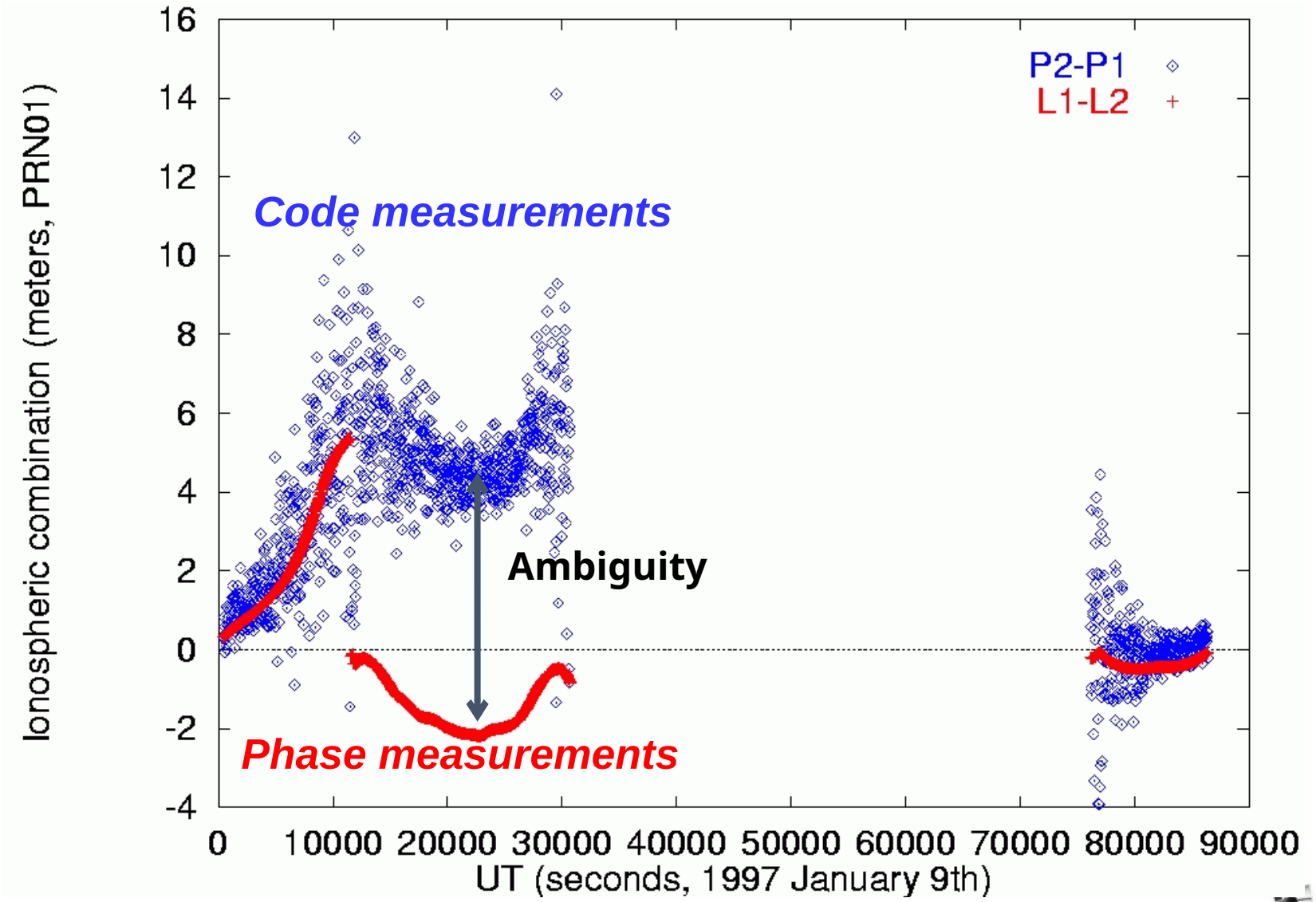


Question #7: Now, any guess or comment about this plot?

-We can see how the ionospheric combinations of **pseudoranges** (AKA codes) and **phase observations** of a given GPS transmitter ("PRN01") from a given receiver, complement each other very well:

-The code measurements are accurate but not precise (obs. noise and multipath >~1 m).

-The phase measurements are not accurate (unknown ambiguity = minus pseudorange at phase lock) but very precise (obs. noise and multipath < 1cm).



Question #8: Finally, have you seen these equations before?

$$L_I \equiv L_1 - L_2 = \alpha \cdot S - \beta \cdot \phi + B_I, \tag{17}$$

$$P_I \equiv P_2 - P_1 = \alpha \cdot S + D_I + D'_I + \epsilon_M + \epsilon_T, \tag{18}$$

Question #8: Finally, have you seen these equations before?

-(17) and (18) **are showing the slant electron content (S) inside GNSS measurements!** Indeed, it is directly given by the ionospheric combination of dual-frequency carrier phases and pseudoranges (L_I & P_I), both the main input data source for GNSS Ionosphere!

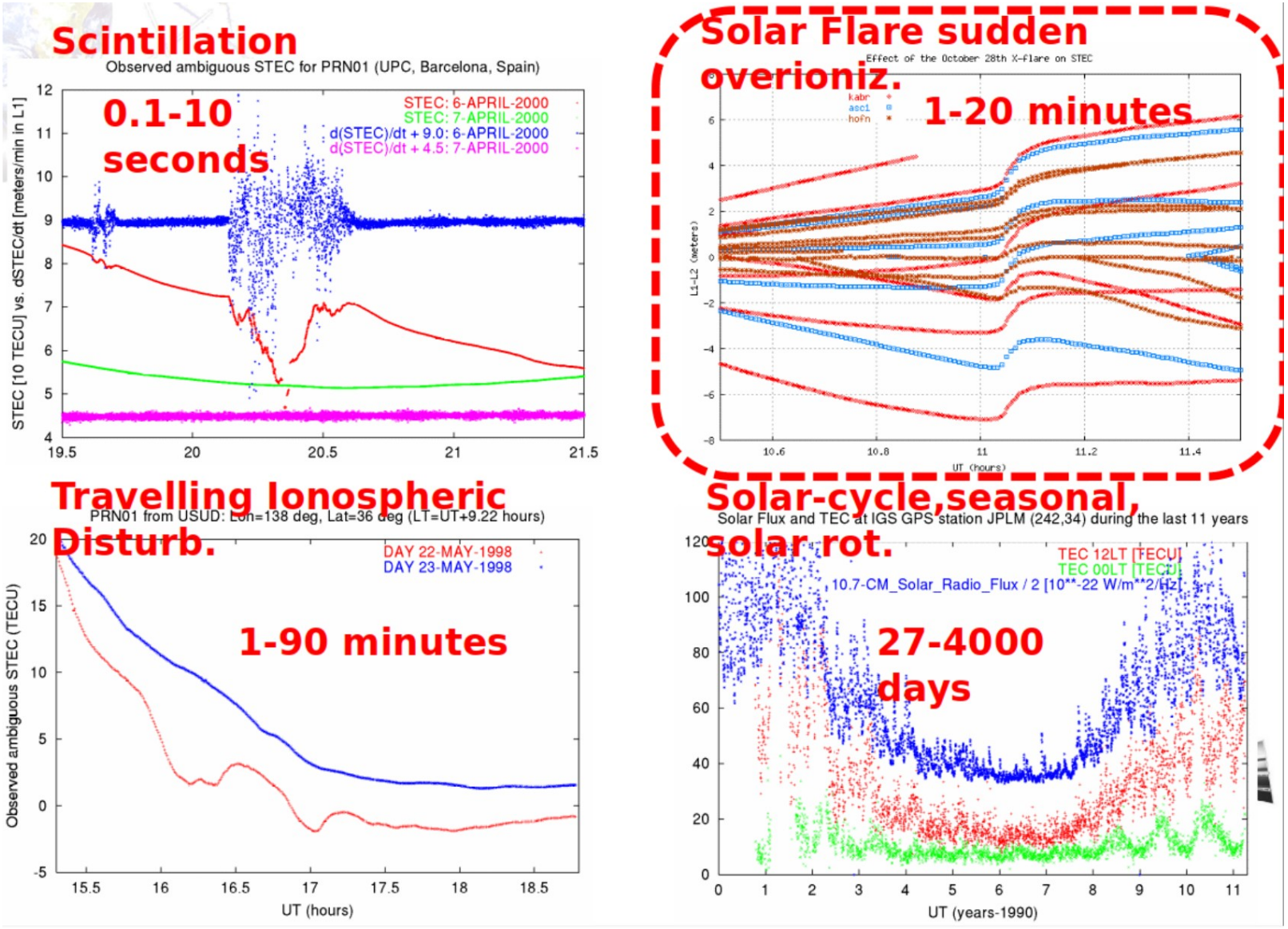
-**Other additional terms, are either constant** at scales of hours (ambiguity BI, Differential Code Biases, DI, DI') or are small and can be very well modelled (wind-up term $\beta * \phi$).

$$L_I \equiv L_1 - L_2 = \alpha \cdot S - \beta \cdot \phi + B_I, \quad (17)$$

$$P_I \equiv P_2 - P_1 = \alpha \cdot S + D_I + D'_I + \epsilon_M + \epsilon_T, \quad (18)$$

where $\alpha = 40.309\left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right) = 1.05 \cdot 10^{-17}\, m^3$, $\beta = c\left(\frac{1}{f_2} - \frac{1}{f_1}\right) = 0.054\,\text{m}$, $B_I = B_1 - B_2$, $D_I = D_2 - D_1$ and $D'_I = D'_2 - D'_1$.[2] In this case, we also made explicit the two main components of the measurement error, both corresponding to the code: the multipath code error ϵ_M and the thermal noise measurement error ϵ_T. Typically, the wind-up term $\beta \cdot \phi$ is a centimeter-level term. For the permanent receivers, this term can be corrected very accurately from their coordinates and orbital information, and it is not discussed explicitly herein.

Question #9: And what about these GNSS obs. footprints?



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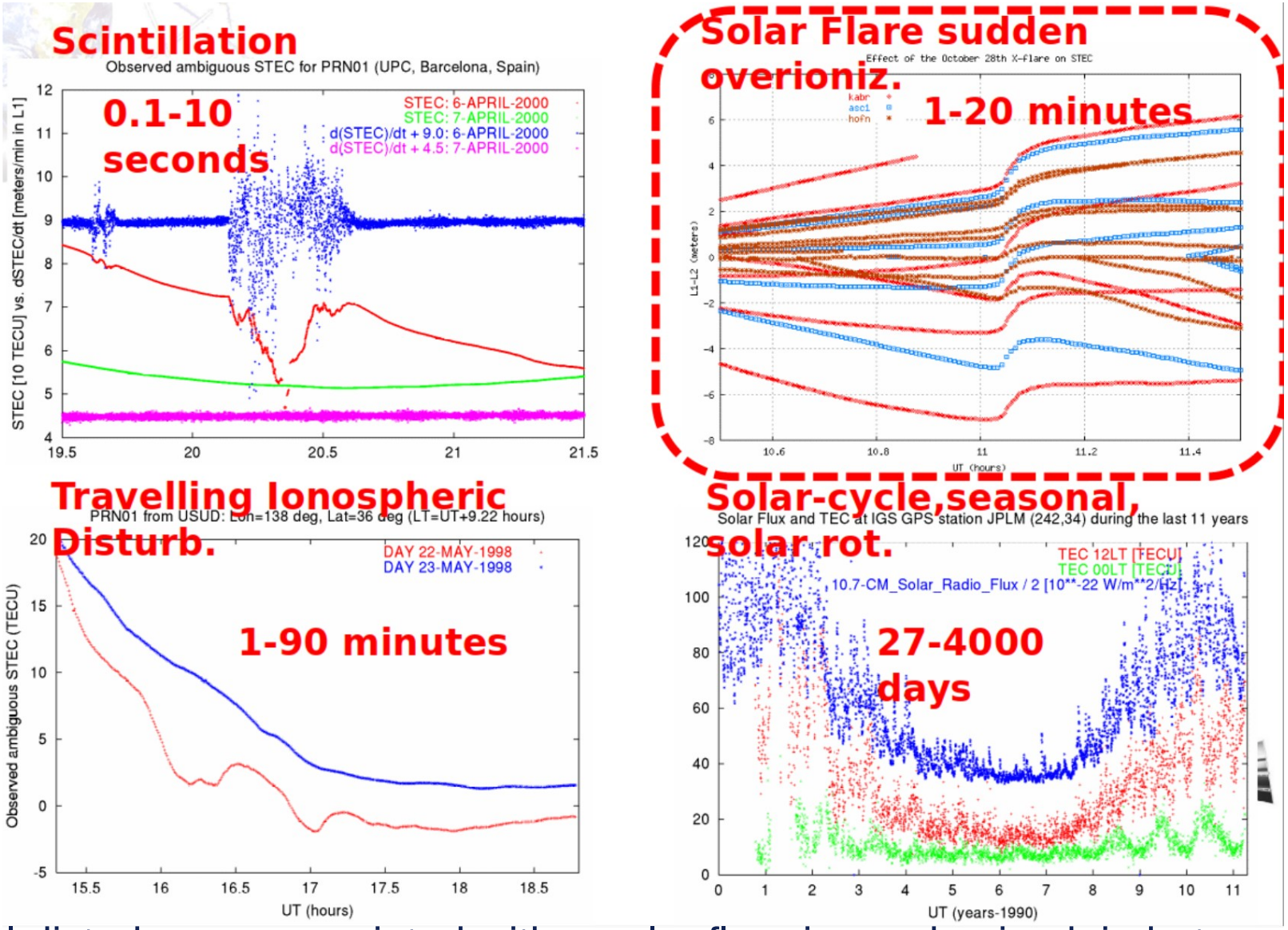

The fundamental disturbance associated with a solar flare is emphasized, in between other disturbances and perturbations that will be treated in some of the lectures.