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Detection of medium-scale traveling ionospheric disturbances with TIMED/GUVI limb observations at mid and low latitude regions

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Background

Medium-scale traveling ionospheric disturbances (MSTIDs) are the most recurrent type of ionospheric irregularities at mid-latitudes but also occur in low-latitude regions. Whether they are due to the propagation of atmospheric gravity waves originating from the lower atmosphere or related to sporadic E layers, their harmonic signature is a common feature that allows them to be easily identified.

MSTIDs have been extensively studied and characterized during the last two decades, mainly using GNSS measurements, ground-based all-sky imagers, radars or ionosondes. However, only few studies aimed to describe their vertical structure using remote sensing observations from space, which is helpful to understand their propagation and their dissipation processes.

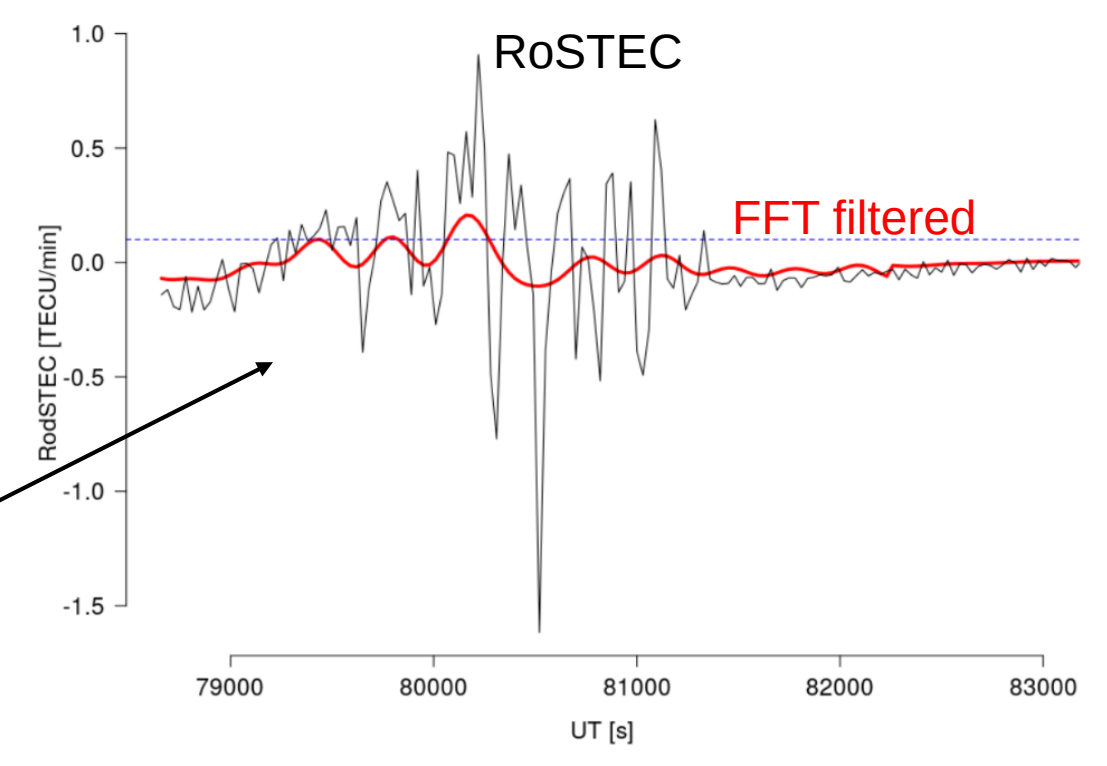
NASA TIMED mission was launched in December 2001 on a 74° inclination orbit at an altitude of 625 km, which allowed covering both low and high-latitude regions. The Global Ultraviolet Imager (GUVI) instrument aimed at remotely sense, among others, the ionospheric ion and electron densities. GUVI performed disk observations and limb scans in five FUV wavelength channels, making it an ideal tool to characterize the vertical structure of the ionosphere as well as to contextualize the study.

The purpose of this work is to use GUVI limb scans to characterize MSTIDs preliminary detected by GPS during maximum background conditions (solar maximum).

1. Detection of MSTIDs with GPS

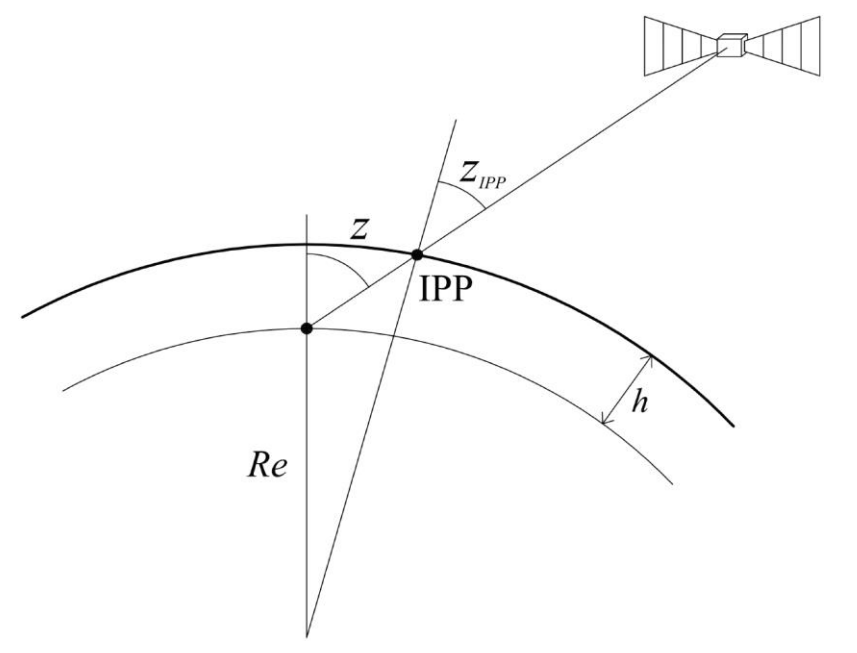
GPS processing

1. L1/L2 Geometry-Free (GF) phase computation → « biaised » slant Total Electron Content (STEC)
2. Epoch-to-epoch differencing → dSTEC
3. Low-cut polynomial fitting to remove orbital and gradients trends → RoSTEC (rate of STEC)
4. Fourier filtering for frequency range 5 – 60min (tuned for small and medium-scale TIDs)
5. 15-min Standard-Deviation of the Fourier-filtered RoSTEC time series → $\sigma_{RoSTEC\_FFT\_filtered}$
6. TID/irregularity detection by applying a detection threshold in $\sigma_{RoSTEC\_FFT\_filtered}$



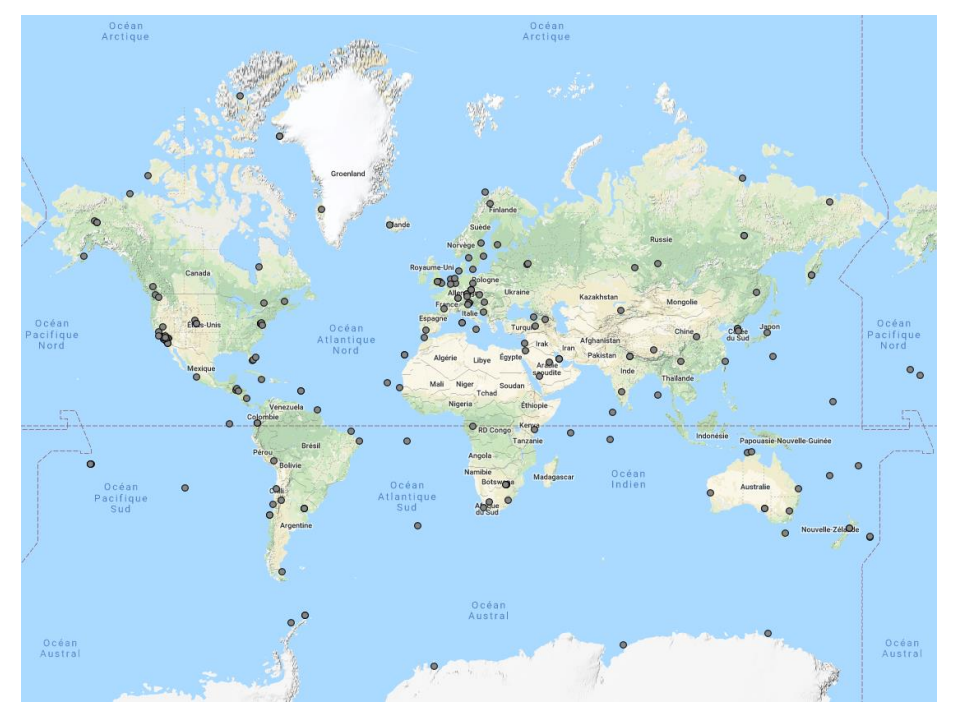
In parallel, computation of ROTI index (5 min resolution)

Mapping of Ionospheric Pierce Points (IPP) at 300 km (single layer model) → geolocation of the MSTID



Data selection

- Solar maximum period: 2002 to 2004
- Geomagnetically quietest or more disturbed days : 10 international Q-days per month / 5 D-days per month
- Nighttime: SZA > 100°
- Selection of GPS stations from IGS legacy network in
  - low-latitudes: around the magnetic equator (+-25° MLAT)
  - mid-latitudes: between 25° and 50° MLAT

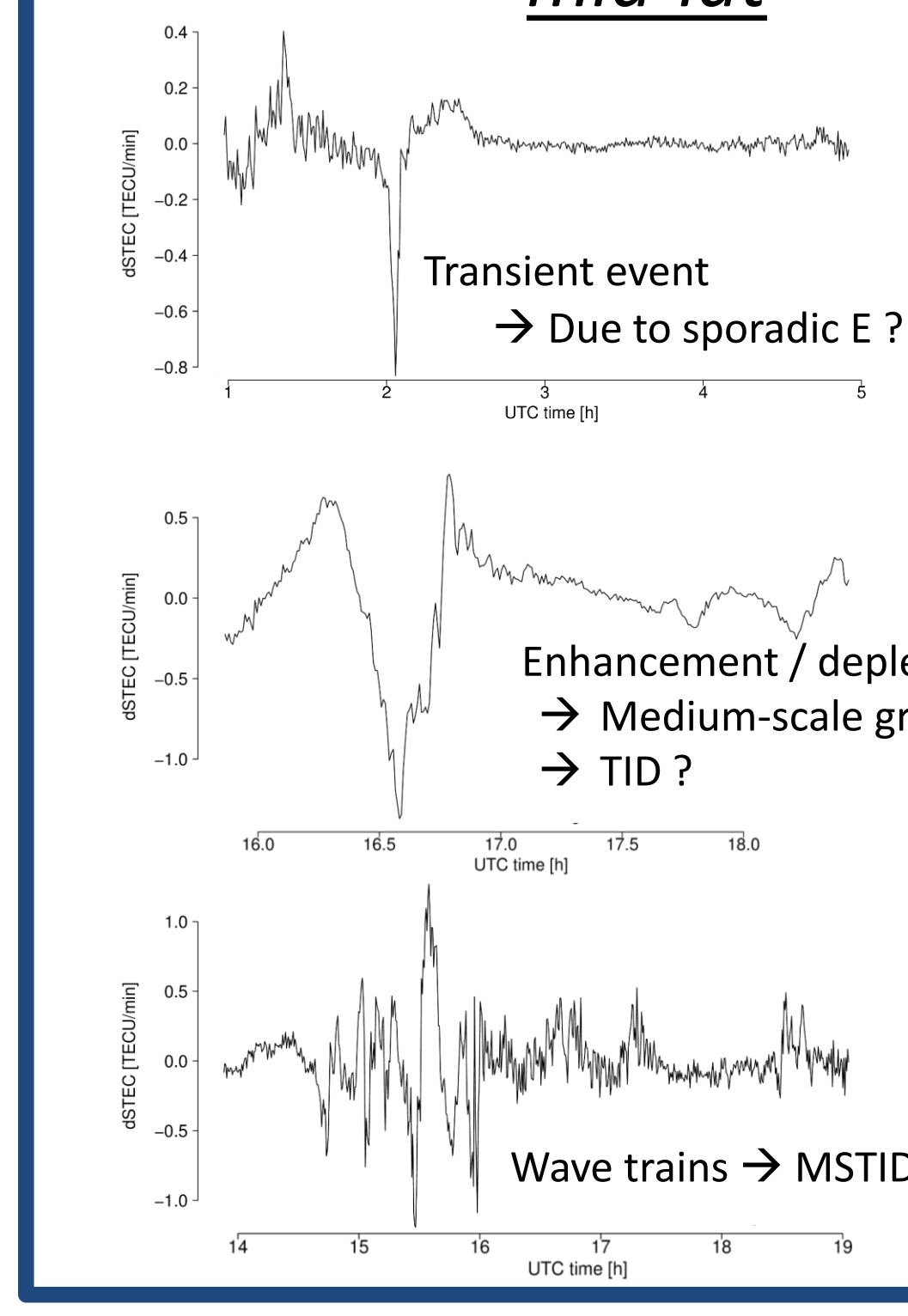


http://www.igs.org/network

Examples of MSTIDs or related features

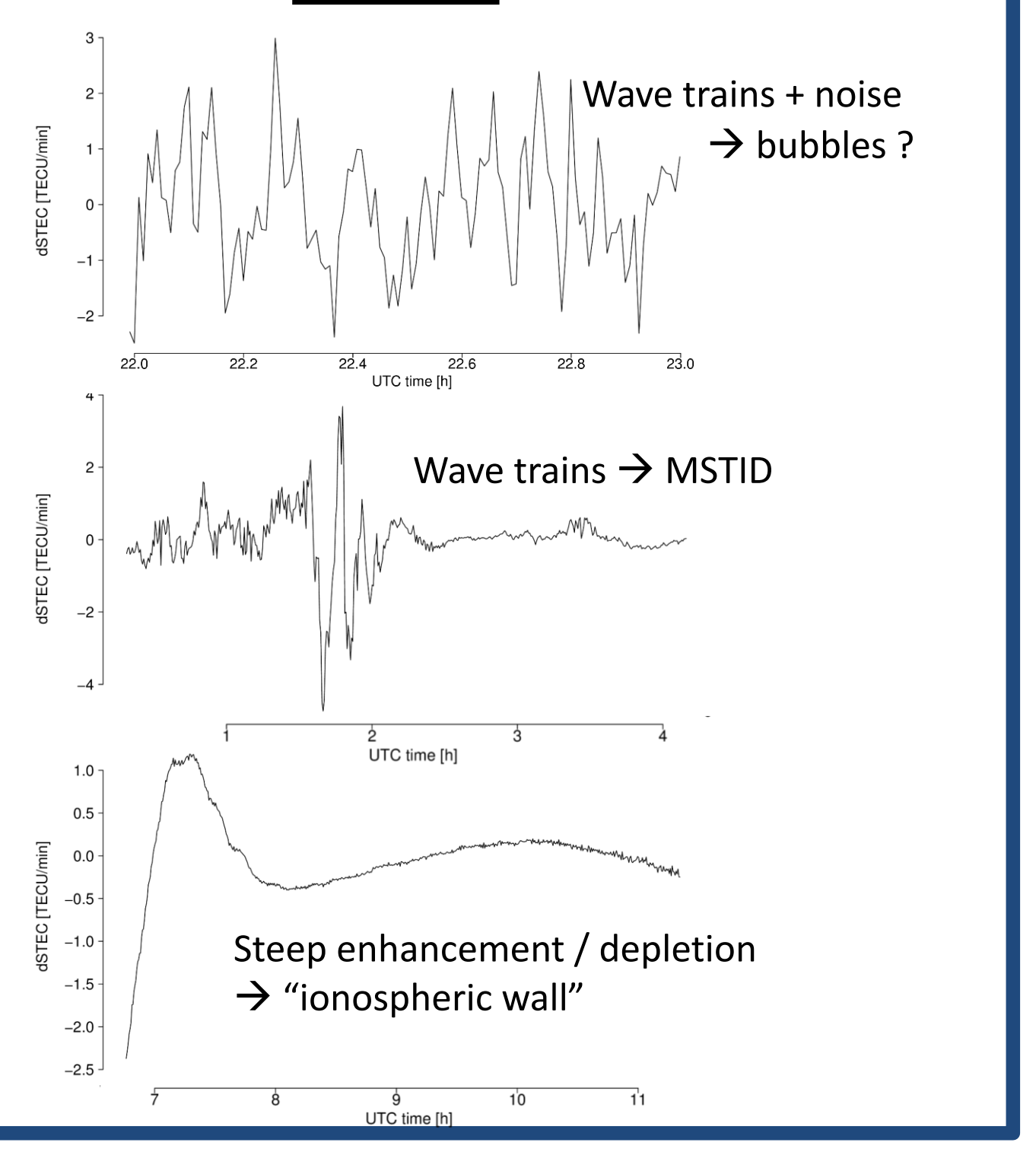
Detection of MSTIDs but also other features (depending on geomagnetic latitude and / or geomagnetic conditions)

mid-lat



Amplitude X2 to X10

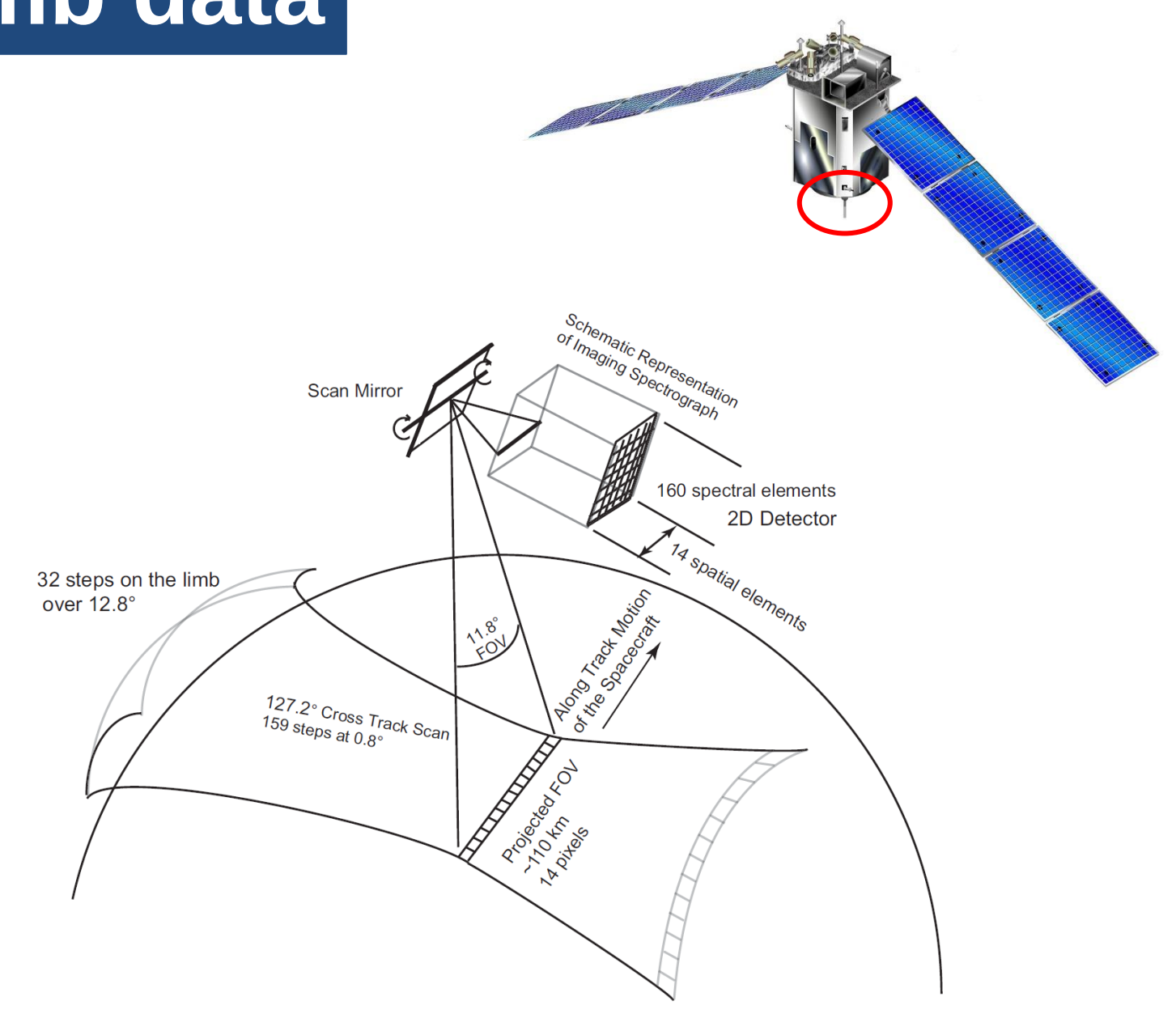
low-lat



2. Handling GUVI limb data

GUVI description

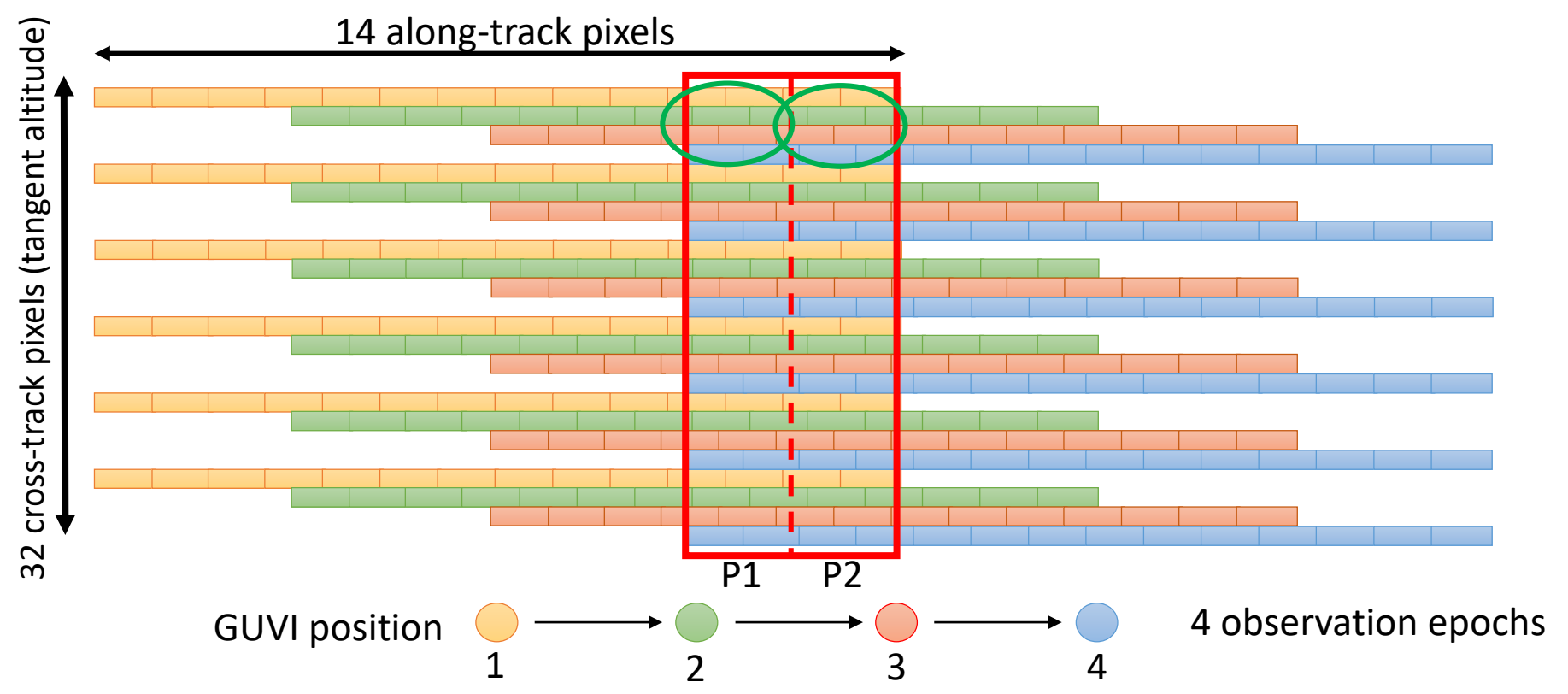
- On-board NASATIMED spacecraft launched in December 2001
- 74° inclination at 625 km altitude (LEO orbit)
- Goal: explore Earth's Mesosphere, Lower Thermosphere and Ionosphere (MLTI)
- Four instruments, among them: the Global UltraViolet Imager GUVI
- Rotating mirror: scan every 15 s
- 14 spatial pixels (along-track)
- 32 pixels per limb profile / 159 pixels per disk image
- Provides both limb and disk measurements
- 5 wavelengths: 121.6 nm, 130.4 nm, 135.6 nm, LBHS, LBHL
- Exposure time very short (0.068s) → need to enhance the SNR !



Credits : Paxton et al. (2004), SPIE proceedings

Improving GUVI L1B limb data (profiles)

- 4 epochs can be superimposed to add pixel counts (or brightness in Rayleighs)
- 9 profiles into 1 super-profile
- 2 super profiles per epoch (P1 and P2)
- Number of counts x 9 → SNR x 300%

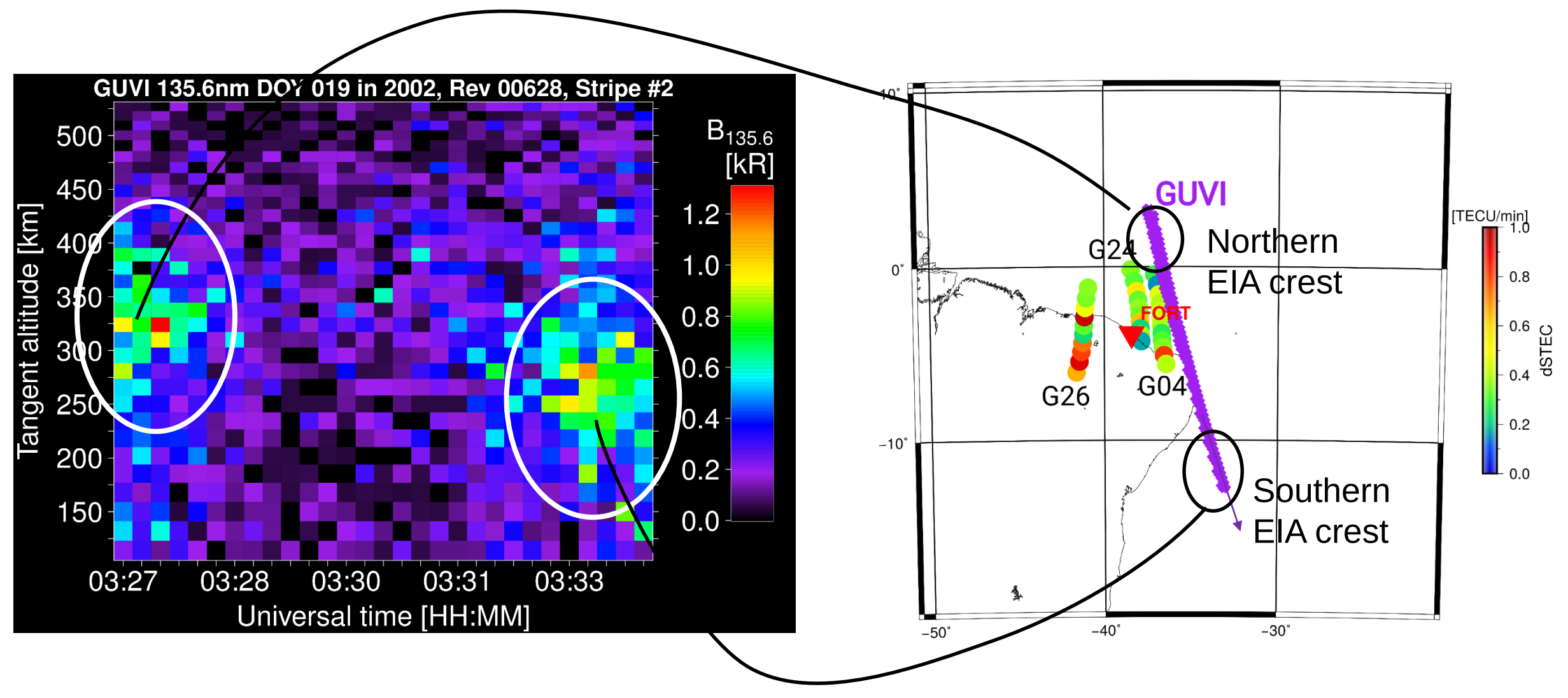


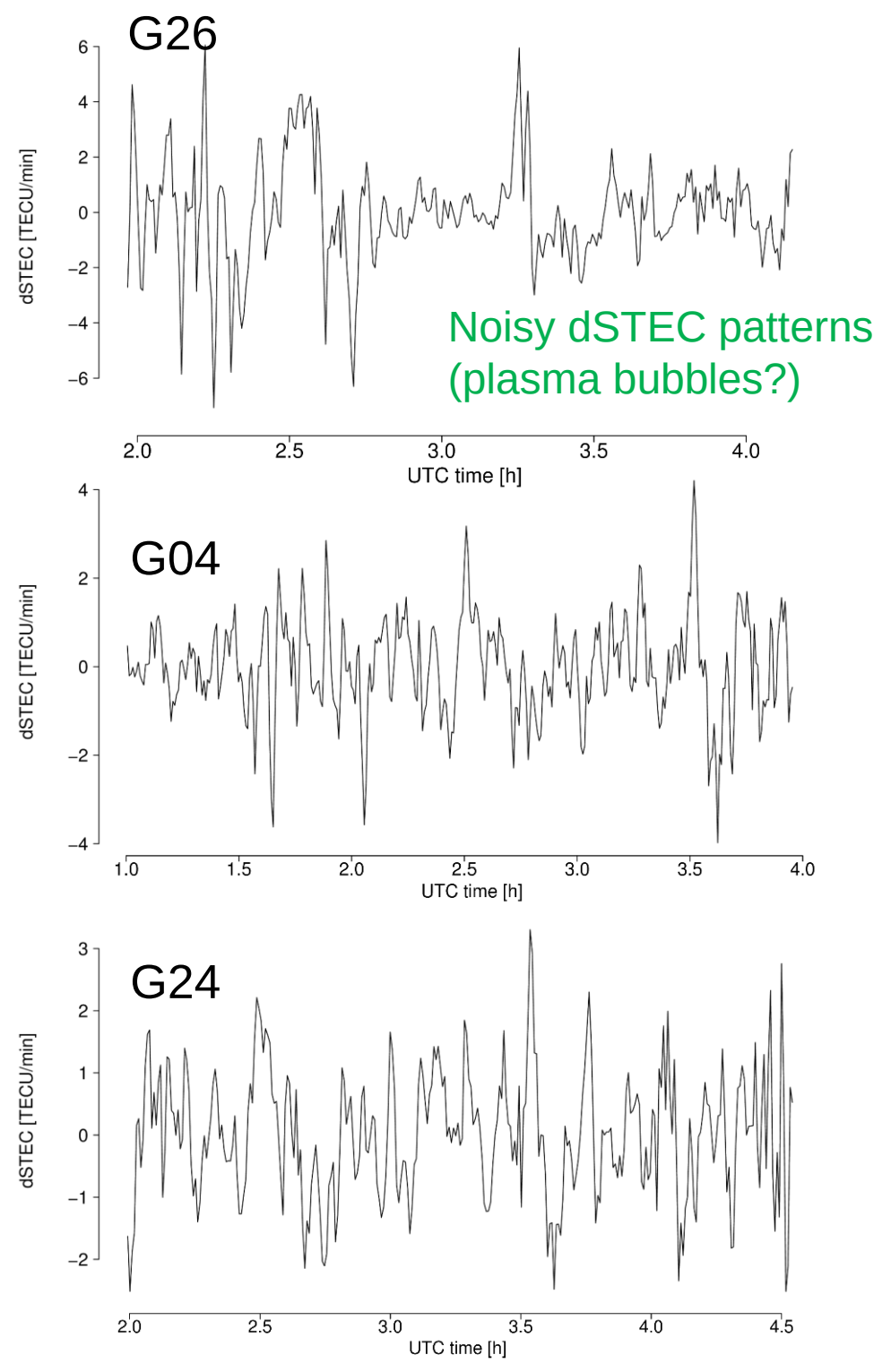
Co-incidental data definition (matching criteria)

- Spatial criterion: distance between GUVI tangent points at 300 km and MSTID-related ionospheric pierce points **< 1000 km**
- Temporal criterion: time difference between GUVI super-profiles and MSTID amplitude peak **< 15 min**.

3. Low-latitude results

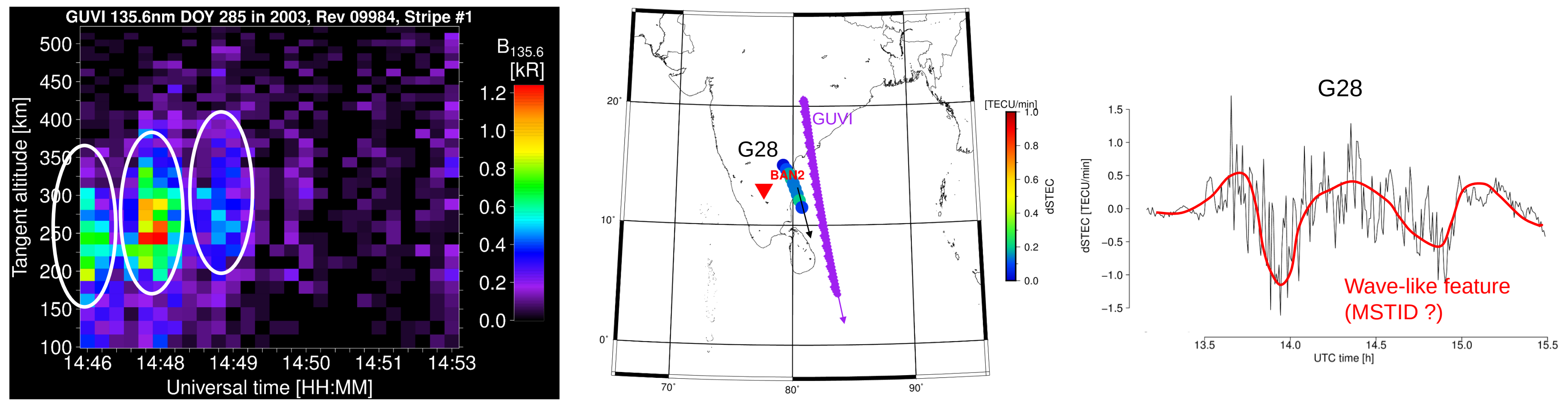
Scintillation example for DOY 019/2002 in Brazil around 03:30 UT (01:15 LT)





- The two EIA crests and their height asymmetry are viewed by GUVI
- Occurrence of GPS scintillations due to km-scale plasma bubbles located on the edges of the crests
- No MSTID visible

MSTID example for DOY 285/2003 in India around 14:45 UT (20:00 LT)

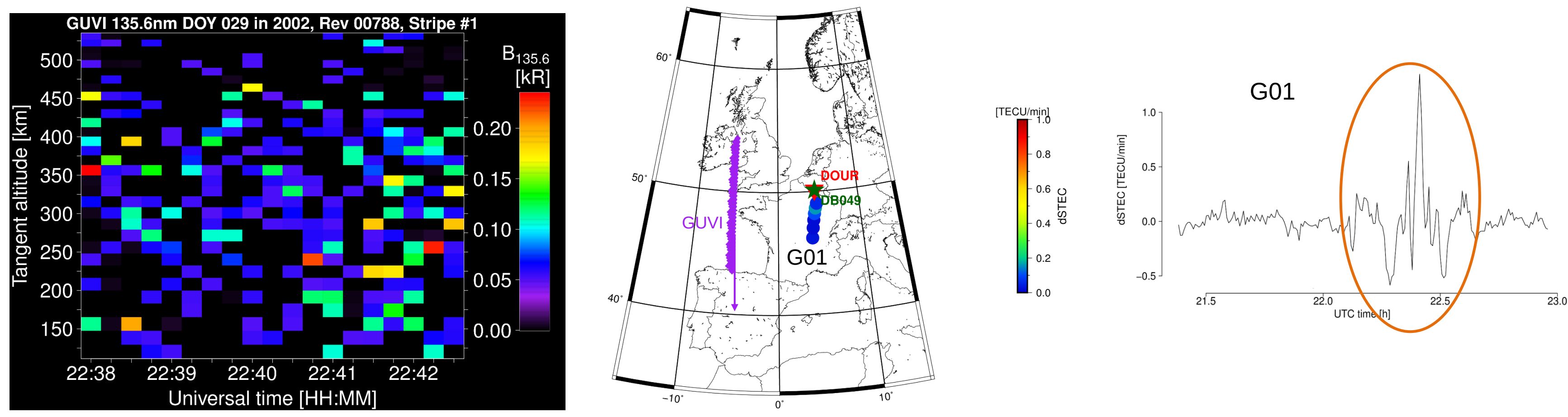


- Three brightness crests visible in GUVI profiles, reflecting MSTID or another wave-like feature observed in GPS
- However, the MSTID vertical structure is not observed within GUVI single profiles → wave damping ? Not a wave ?
- The mean altitude of the successive crests increases → plasma uplift (post-sunset fountain effect)
- On GPS data: superimposition of noisy structure (scintillation) due to km-scale plasma bubbles

4. Mid-latitude results

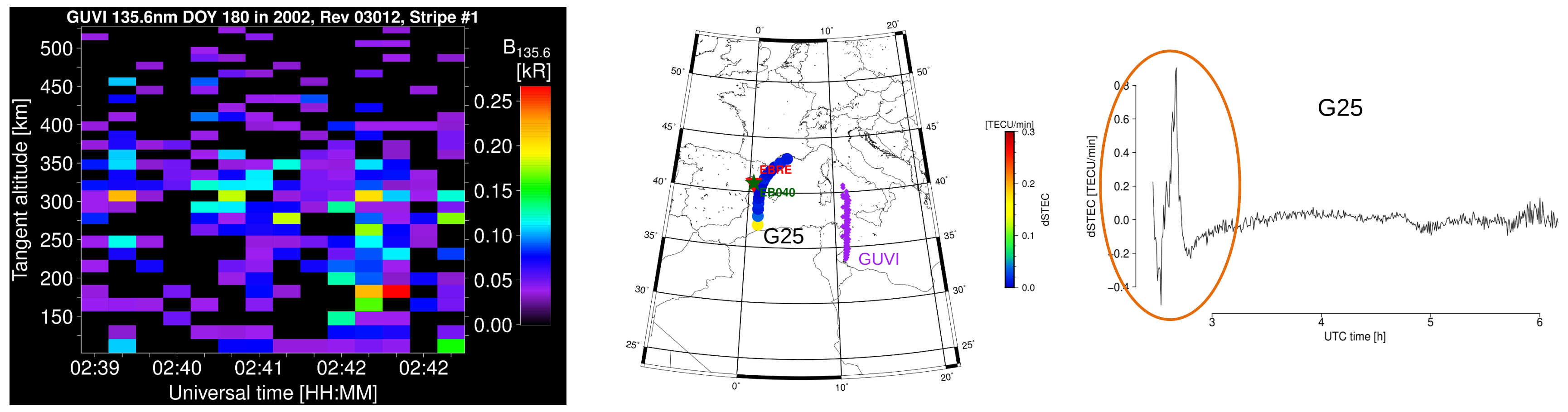
Selection of the largest amplitude MSTIDs in GPS mid-latitude data from 2002 to 2004 (solar maximum)

Nighttime MSTID over Belgium, DOY 029/2002 around 22:30 UT/LT



- Large amplitude MSTID detected in GPS data but did not produce any signature in GUVI: SNR too weak
- The slight increase of GUVI brightness is probably due to decreasing latitude

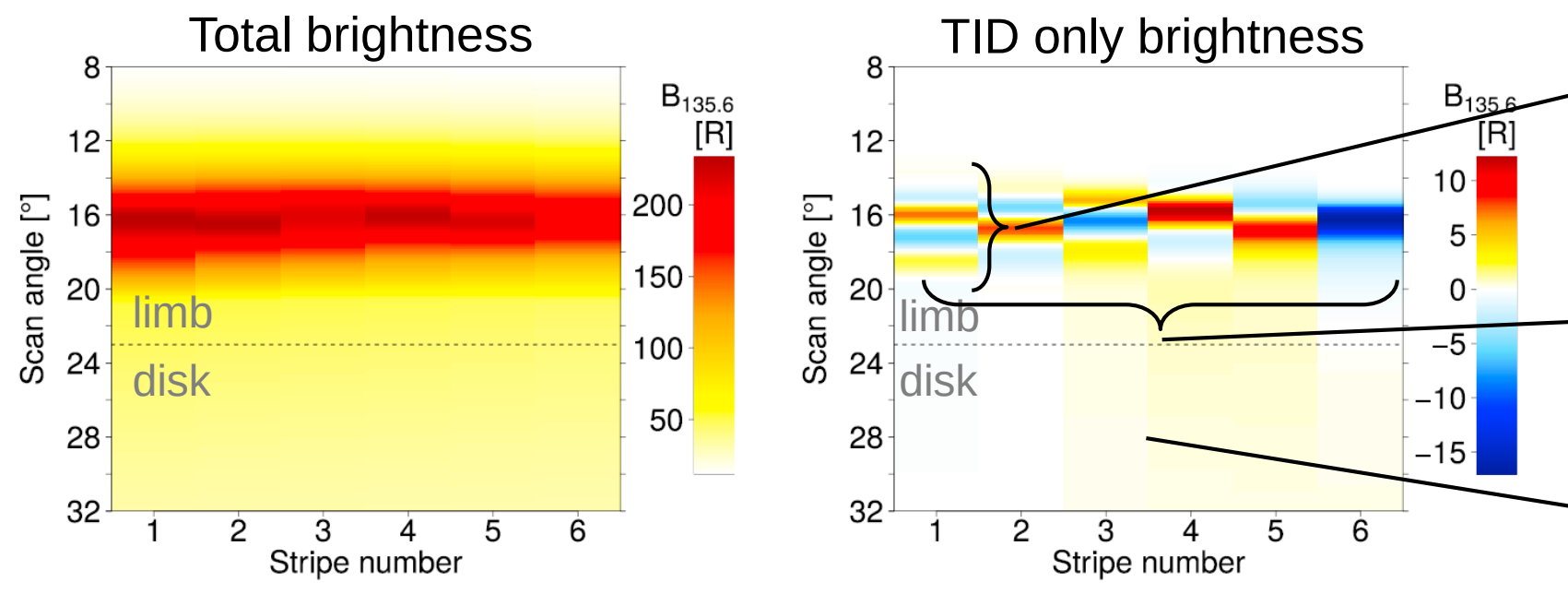
Nighttime MSTID over Spain, DOY 180/2003 around 02:30 UT/LT



- Same as above: large amplitude MSTID detected in GPS but not in GUVI

Summary and future work

- Analysis of nighttime ionospheric disturbances during solar maximum with GPS and GUVI 135.6 nm limb data
- Computation of GUVI super-profiles to enhance the signal-to-noise ratio by 300%
- Analysis in two steps:
  1) irregularity detection using GPS-TEC data over a global GPS network
  2) identification of coincidental GUVI – GPS data
- Over low latitudes:
  a) equatorial arcs and associated irregularities are visible in GUVI data and bring substantial information to interpret the physical nature of the phenomena leading to GPS-TEC disturbances
  b) appearance of MSTID-like features that cannot be resolved in GUVI profiles → are there some other (than TIDs) wave-like phenomena leading to harmonic signatures in GPS ?
- Over mid-latitudes: detection of MSTIDs or other wave-like features is very unlikely due to the weak SNR, even during high solar activity and using profiles with enhanced SNR
- Future developments imply the ICON mission (launched in October 2019), and in particular the FUV instrument:
  a) Increased sensitivity for ICON due to larger exposure time: 1 count ≈ 1.7 Rayleighs (ICON) V.S. 128 Rayleighs (GUVI)
  b) MSTID detection would be possible during solar maximum conditions but will be strongly dependent on the geometry between the wave and the FUV lines of sight: see Wautelet et al. (2019) for details.
  c) Example of ICON-FUV response in 135.6 nm images during the passage of a simulated MSTID:



On the limb: high-resolution limb profiles of ICON-FUV will allow to retrieve the vertical wavelength

On the limb: images will allow to measure the horizontal wavelength

On the disk: the MSTID signature will be to faint to be detected by ICON-FUV

Six-stripe images of B135.6 on 21 March 2014 at 00:00 UT. The left panel depicts the total brightness due to both background and TID contributions while the right panel plots the single contribution of the TID (source: Wautelet et al. (2019), JGR Space Physics, 124, doi 10.1029/2019JA026930)

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