The South America VLF Network – SAVNET: Last results and new research perspectives

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- ULTRA-MSK + (as of mid-2016) data access thesavnet724.wordpress.com/

- Modelling ionospheric response to SGR, and energetic protons (future)
  GEANT 4 + LWPC (PD: Sourav Palit)

- daytime ionospheric sensitivity versus solar activity cycle (see Macotela et al.)
  F_{min} (> 6 keV) compared to solar Lyman-α photon flux

- D-region absorption model – D-RAP (Claudio Machado)
  improvement ?

- The South Atlantic Anomaly – SAA (Antonio Magalhães, Liliana Macotela)
  First evidence of the effects on the quiescent reference height

- Nighttime reference height (Hn) (Jorge Samanes, Antonio Magalhães)
  TT → Hn modulation on different timescale

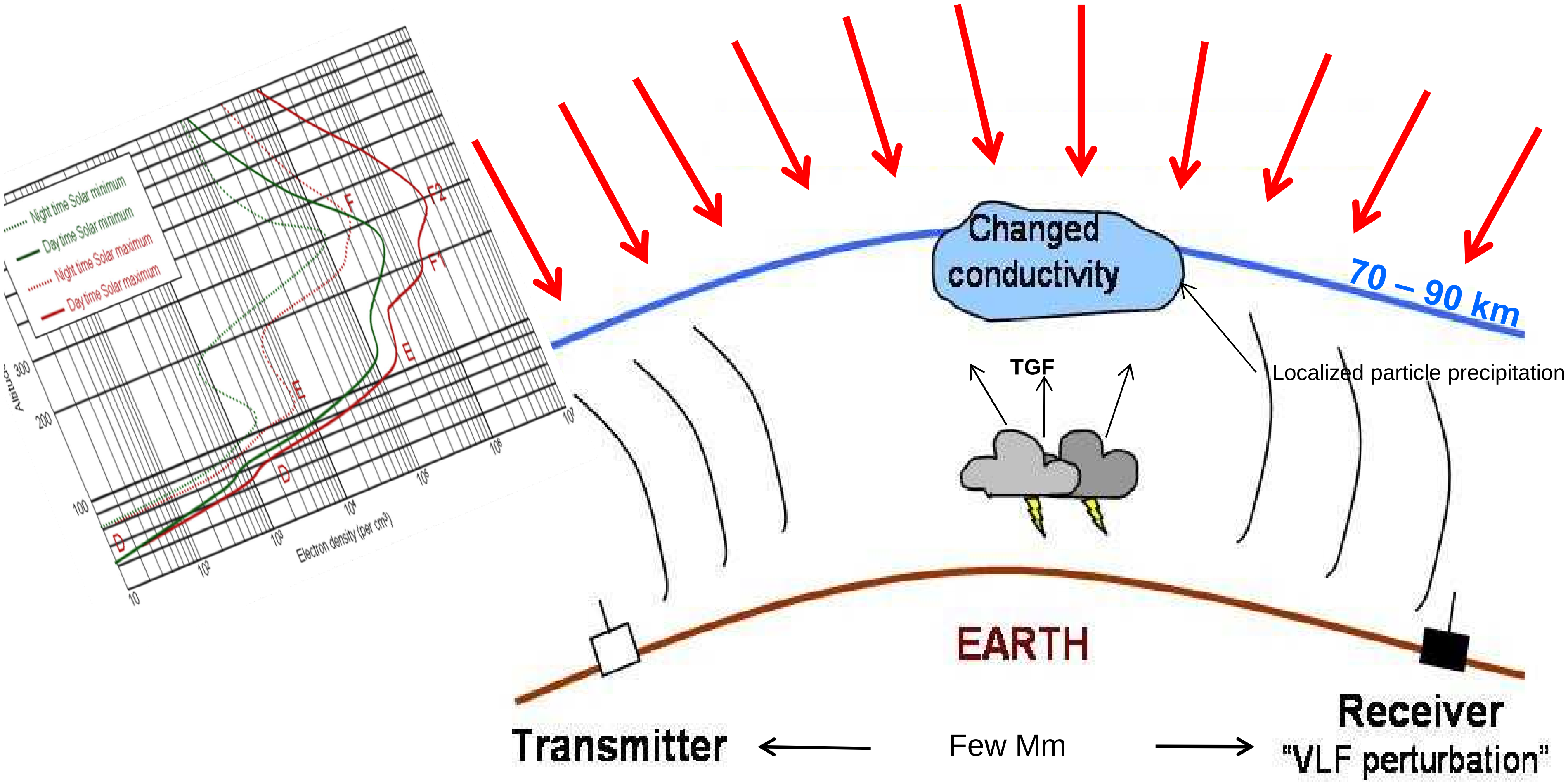
- Seismic EM effects: Changes invertebrate activity and concurrent perturbations in the ionosphere prior to a large (M=7) earthquake in Peru

Ionospheric Disturbances

Photons and/or energetic particles → ionization excesses → changes of the electrical conductivity

→ VLF propagation anomalies → VLF phase and amplitude changes

<u>Solar</u>: quiescent, Ly-α, X-rays (flares), particles (SEPs); <u>Non-Solar</u>: X-rays, GRB, flares from SGR



SAVNET










~ 20 academic degrees

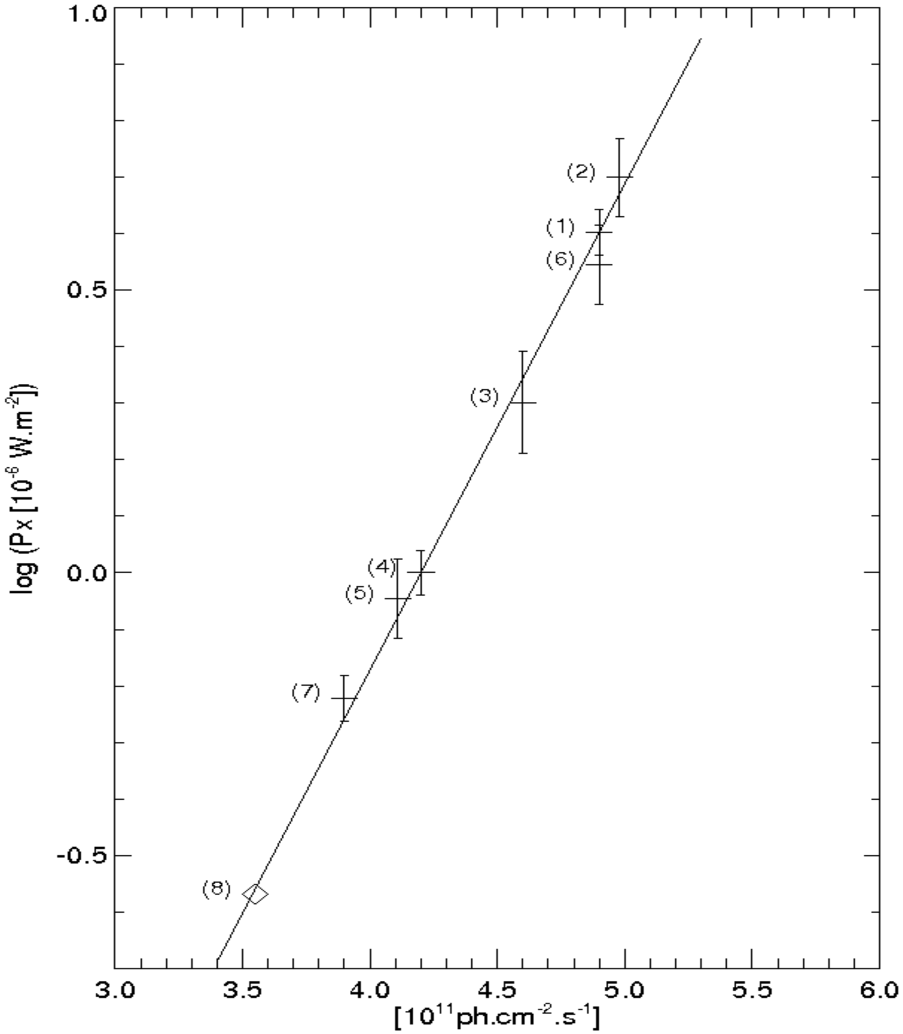
20 papers



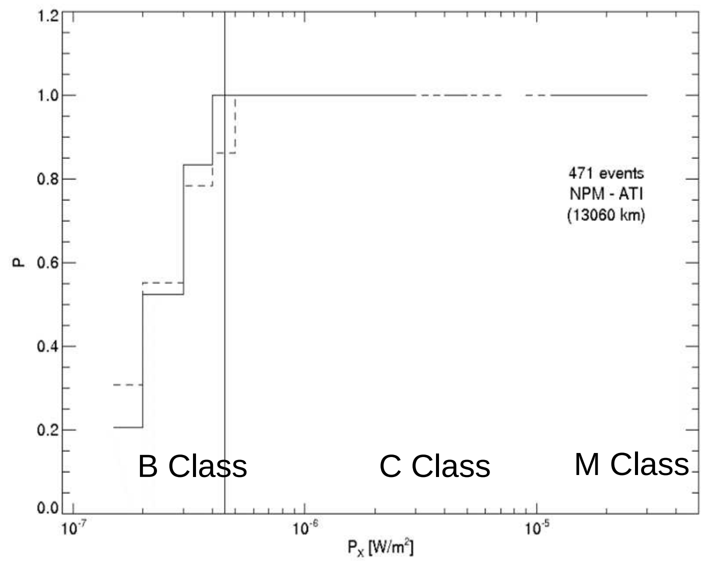

Capacity building

Formation of human ressources

TRANSIENT SOLAR FORCING: FLARES



B 4 (and higher) Class events are detected with 100 % probability



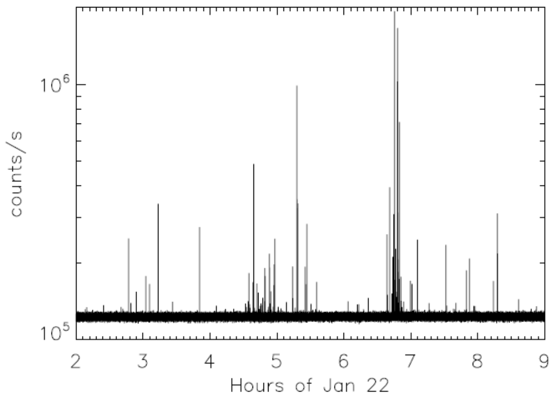
The minimum detectable soft X-ray flux is correlated with the averaged Lyman-α flux : the higher the solar activity the higher Px

↓

Lyman-α solar radiation maintains the quiet ionospheric D-region (Nicolet & Aikin 1960)

SGR J1550-5418 on 2009, January 22

ACS/SPI-INTEGRAL (~75 keV)



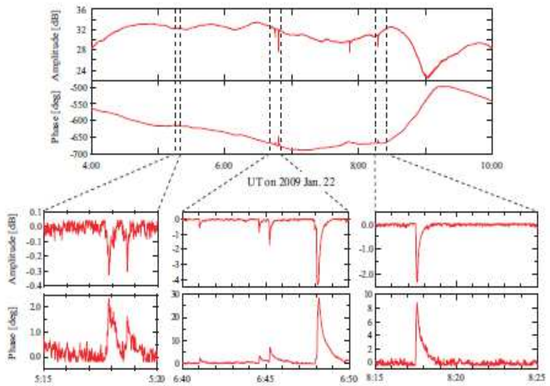


Figure 2. Amplitude and phase variations of a VLF signal from NPM transmitter (21.4 kHz), which were observed at ATI (see Figure 1) from 4:00 UT to 10:00 UT on 2009 January 22. Lower figures are background-subtracted blown-ups at time ranges during which short repeated SGR bursts were detected (see also Table 1).

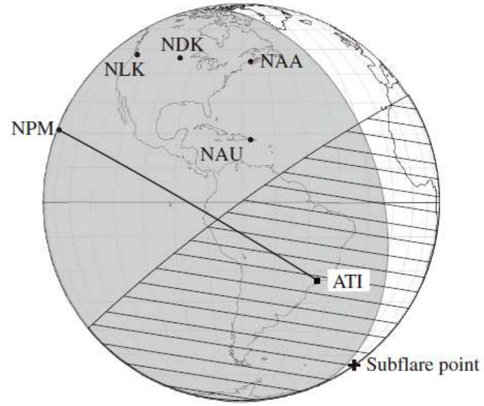
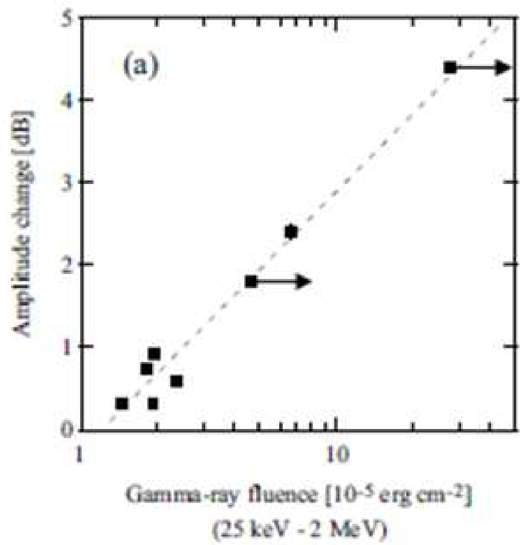
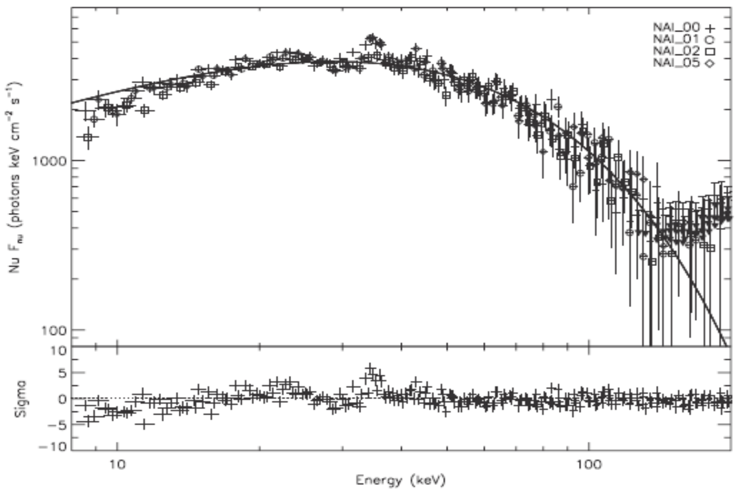


Figure 1. VLF propagation path from NPM transmitter (Hawaii) to ATI observing station (São Paulo, Brazil). Also shown are the locations of other four VLF transmitters (NLK, NDK, NAA, and NAU). Shaded hemisphere indicates the nightside part of the Earth at 6:48 UT, when the largest burst occurred (see Table 1). The part of the Earth illuminated by gamma rays at 6:48 UT is also drawn by dashed area.

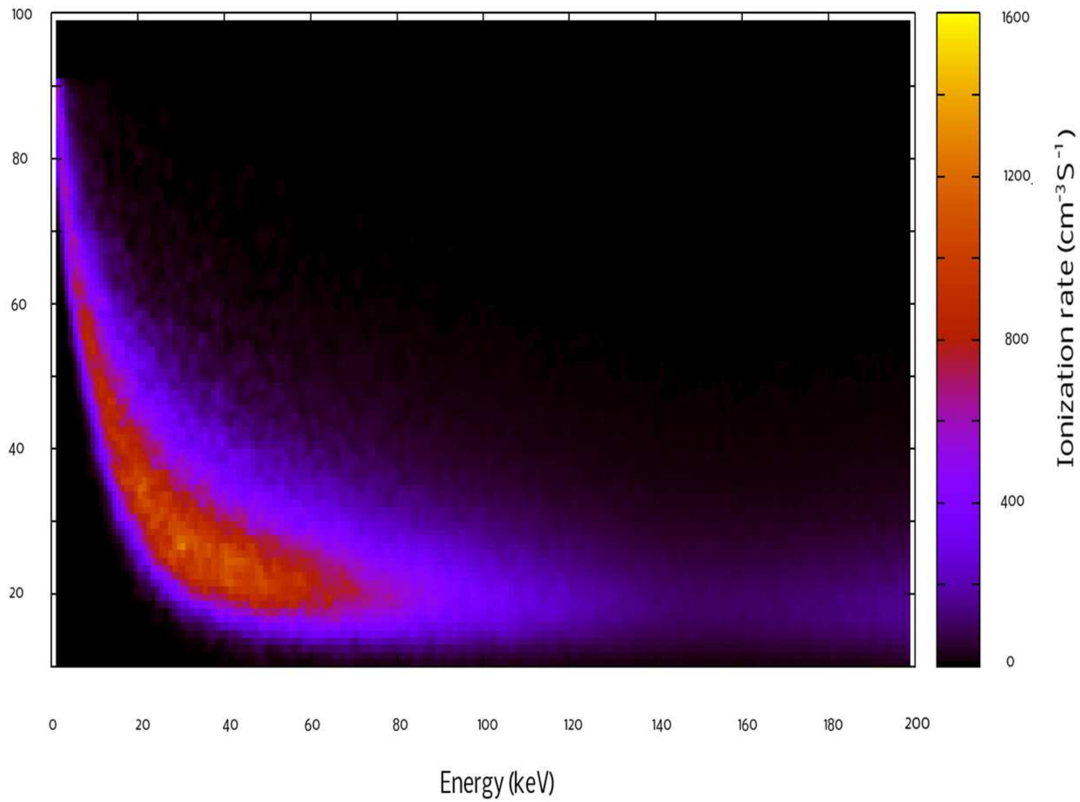
The VLF technique can be used to study remote objects of great astrophysical importance. The fact that the nighttime ionosphere can be disturbed by **intermediate cosmic X-ray bursts**, and not only by **giant ones**, indicates that the **frequency of detection of such events could be improved**. The VLF detection appears as an observational diagnostic that complements their detection in space, in particular when space observations are not available, for example during **Earth's occultation** or above the **South Atlantic Anomaly region**, or suffer from **saturation**. The VLF technique can be used to constrain the **low energy photon spectrum**.



SGR J1550-5418 on 2009, January 22

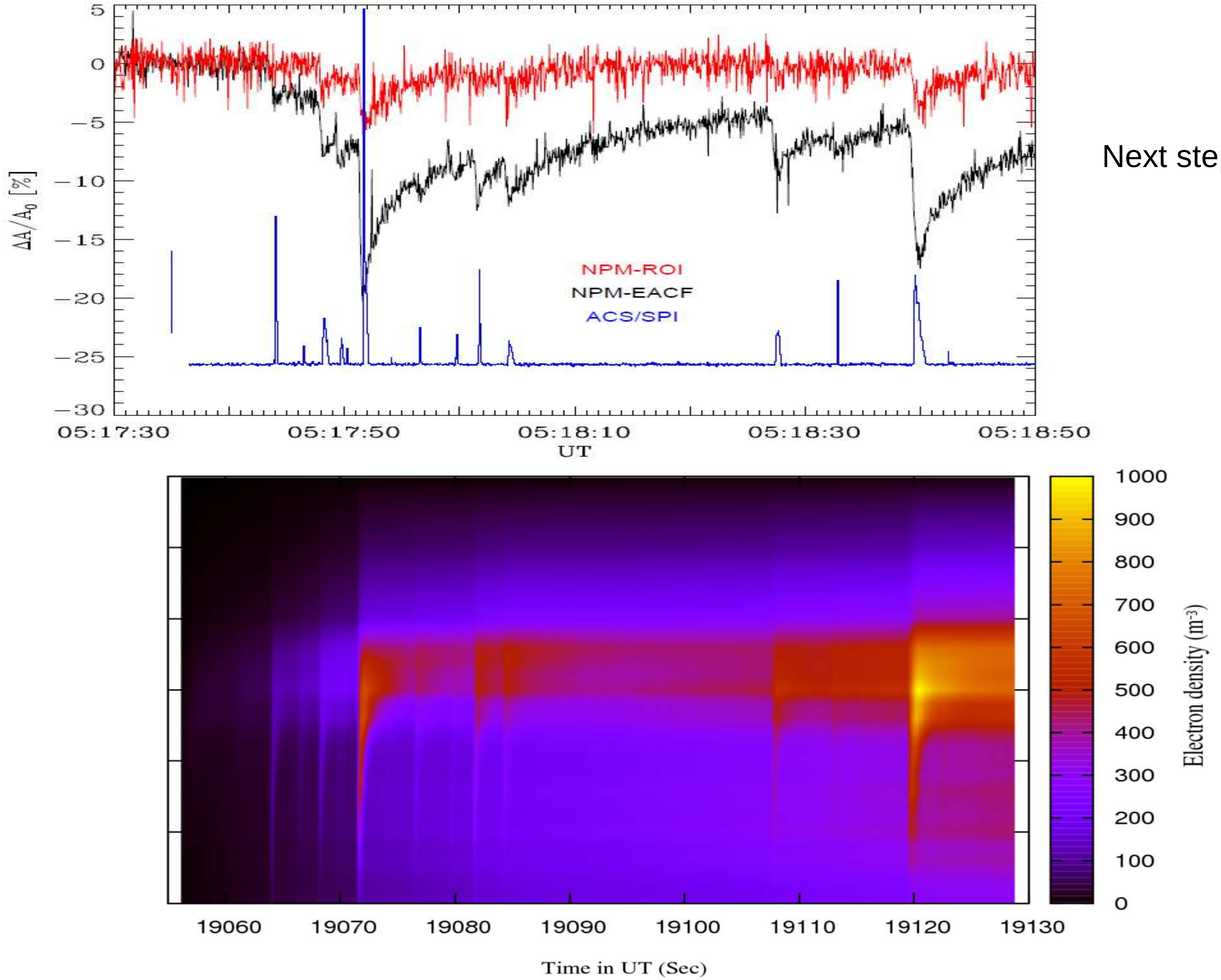


05:17:51.3 UT



286 bursts were detected by FERMI/GBM NaI detectors (Van der Horst et al. 2012, ApJ) in the 8 keV – 1 MeV range.

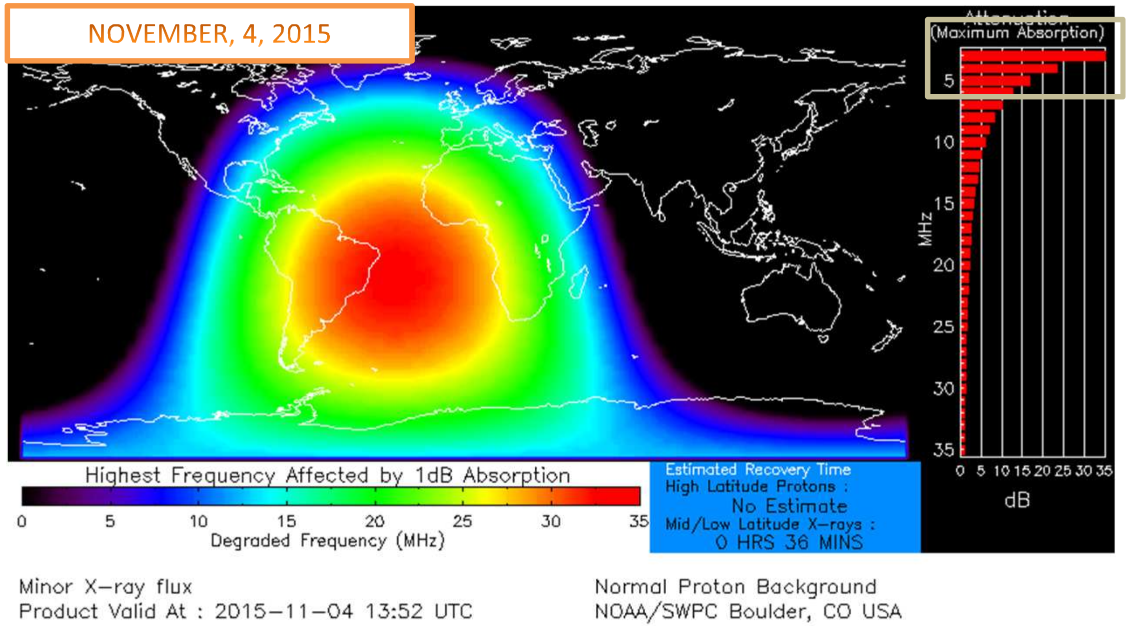
- OTTB with k_BT ~ 39 keV fits well the data for most bursts



Next step: LWPC

Ionospheric absorption

D-RAP at peak time of M3.7 solar flare.



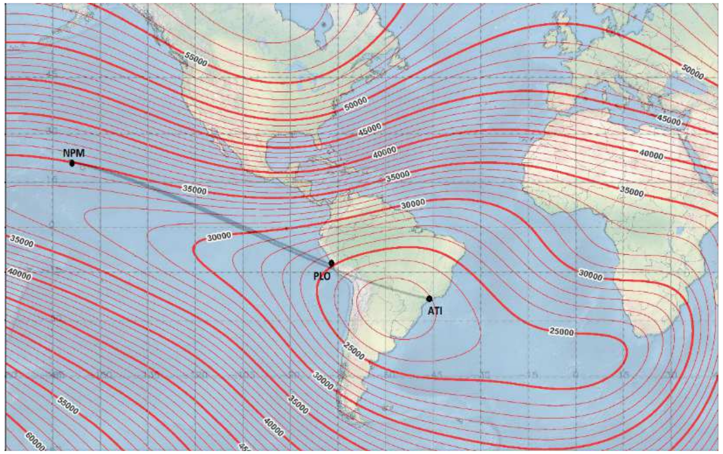
$HAF\ [MHz] = 10 \cdot \log[\ \mathbf{flux\ (W \cdot m^{-2})}\ ] + 65$

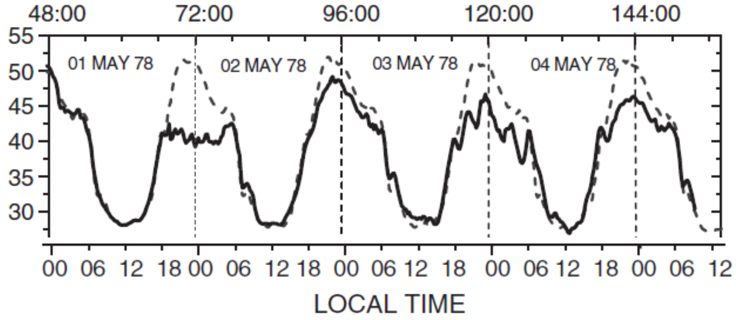
Absorption at any given frequency f (in MHz):

$$A(f) = (f_0/f)^{3/2} A(f_0) \quad \text{[dB]}$$

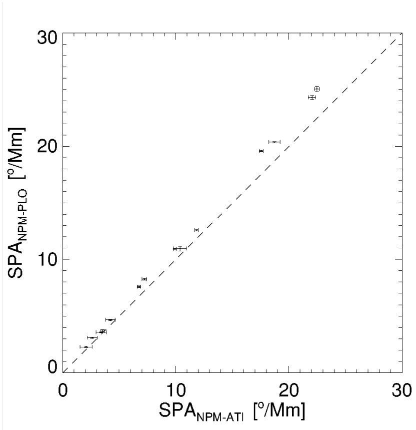
- Photon energy ?
- Model verification: Riometers
  - high latitude
  - solar mw emission
- Electron density

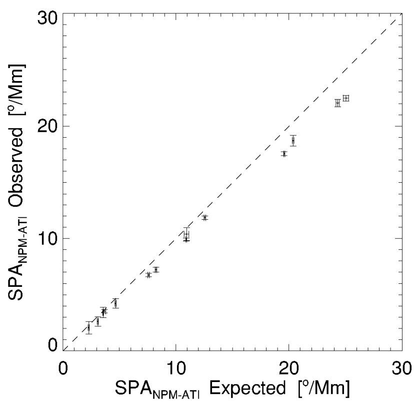
Magnetic Anomaly

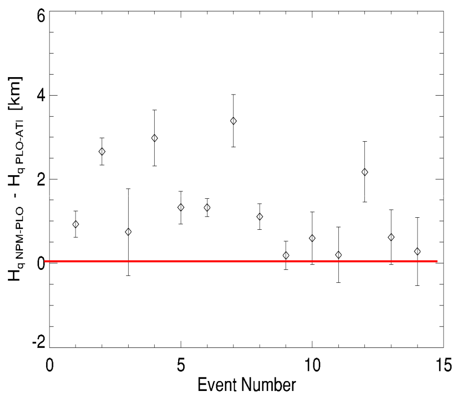


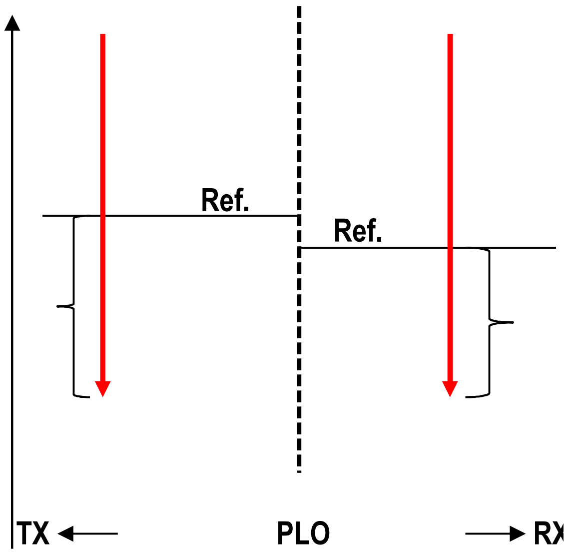


Intense magnetic storm (Abdu et al. 2005)









Our observations indicate that the quiescent reference height is lower by 1 - 3 km within the PLO – ATI portion of the propagation path

First evidence of the effect of the magnetic anomaly on the quiescent D-region reference height

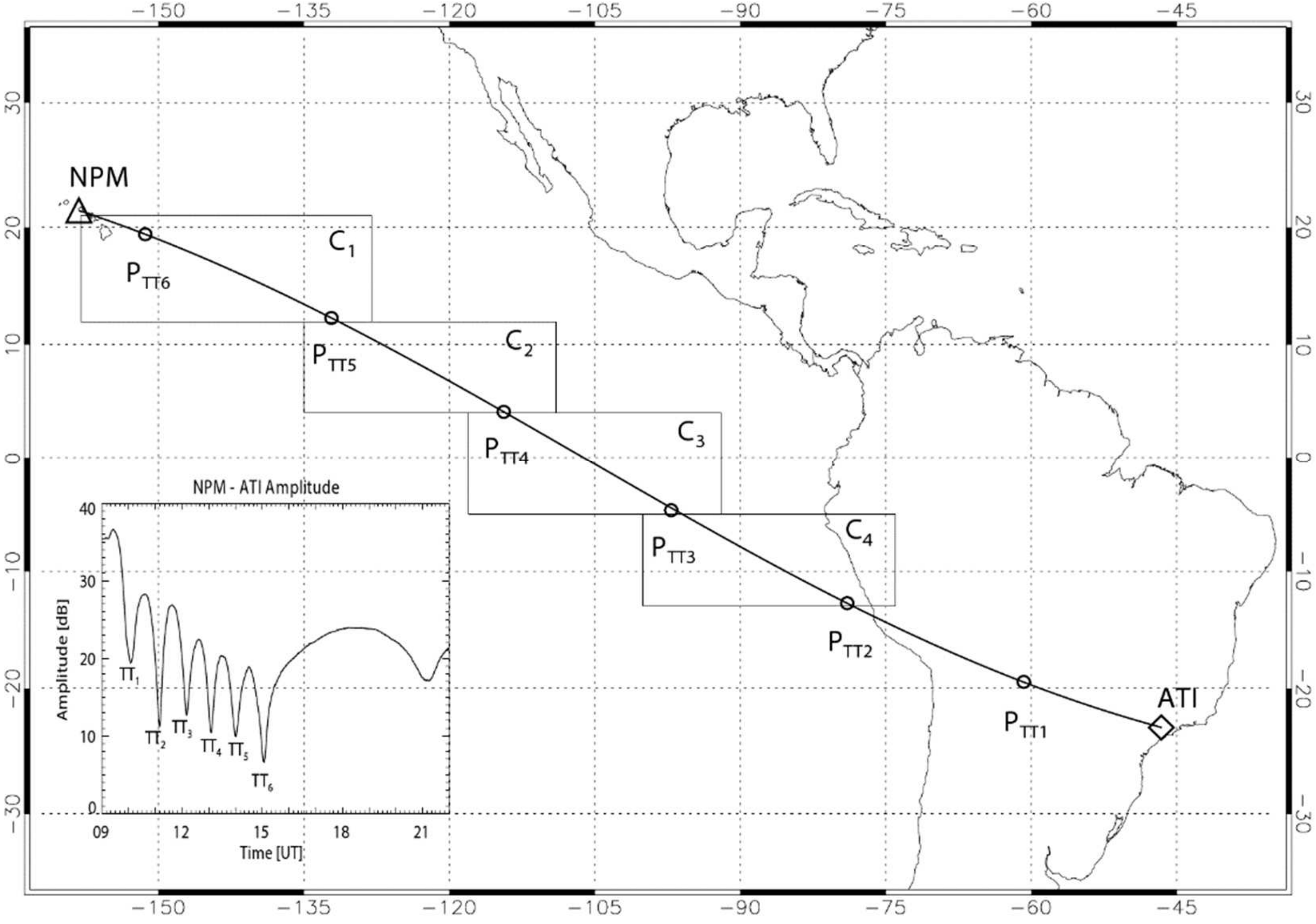
CONCLUSIONS

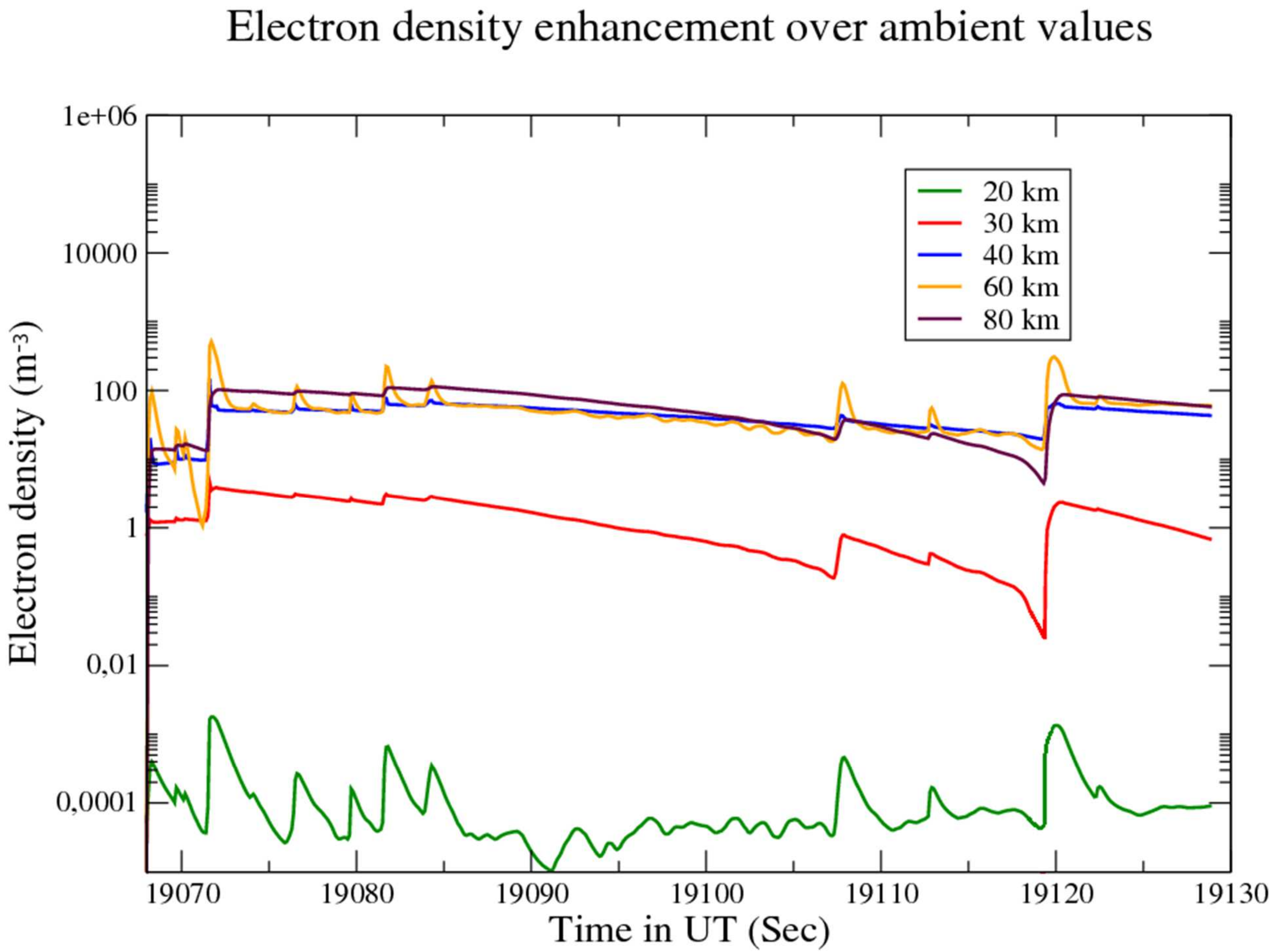
The lower ionosphere plasma is a medium very sensitive to external forcing: radiation, energetic particle fluxes.

The VLF technique (remote sensing of the lower ionosphere) which uses very simple and cheap instrumental facilities is therefore a very promising tool to study many aspects of the Space Weather dynamics, as long-term (solar cycle) and transient solar phenomena (flares, SEPs).

The same technique can also be used to study remote objects of great astrophysical importance. The VLF detection of high-energy astrophysical bursts appears as an interesting observational diagnostic that complements their detection in space, in particular when space observations are not available, for example during Earth's occultation or above the South Atlantic Anomaly region, or suffer from saturation.

Nighttime Ionospheric Reference Height





Electron density enhancement over ambient values
1e+06
10000
100
1
0,01
0,0001
Electron density (m-3)
19070
19080
19090
19100
19110
19120
19130
Time in UT (Sec)
20 km
30 km
40 km
60 km
80 km

Changes invertebrate activity and concurrent perturbations in the ionosphere prior to a large (M=7) earthquake in Peru

Rachel A. Grant, Jean-Pierre Raulin; Friedemann T. Freund