The South America VLF Network - SAVNET: Achievements, latest results and future directions

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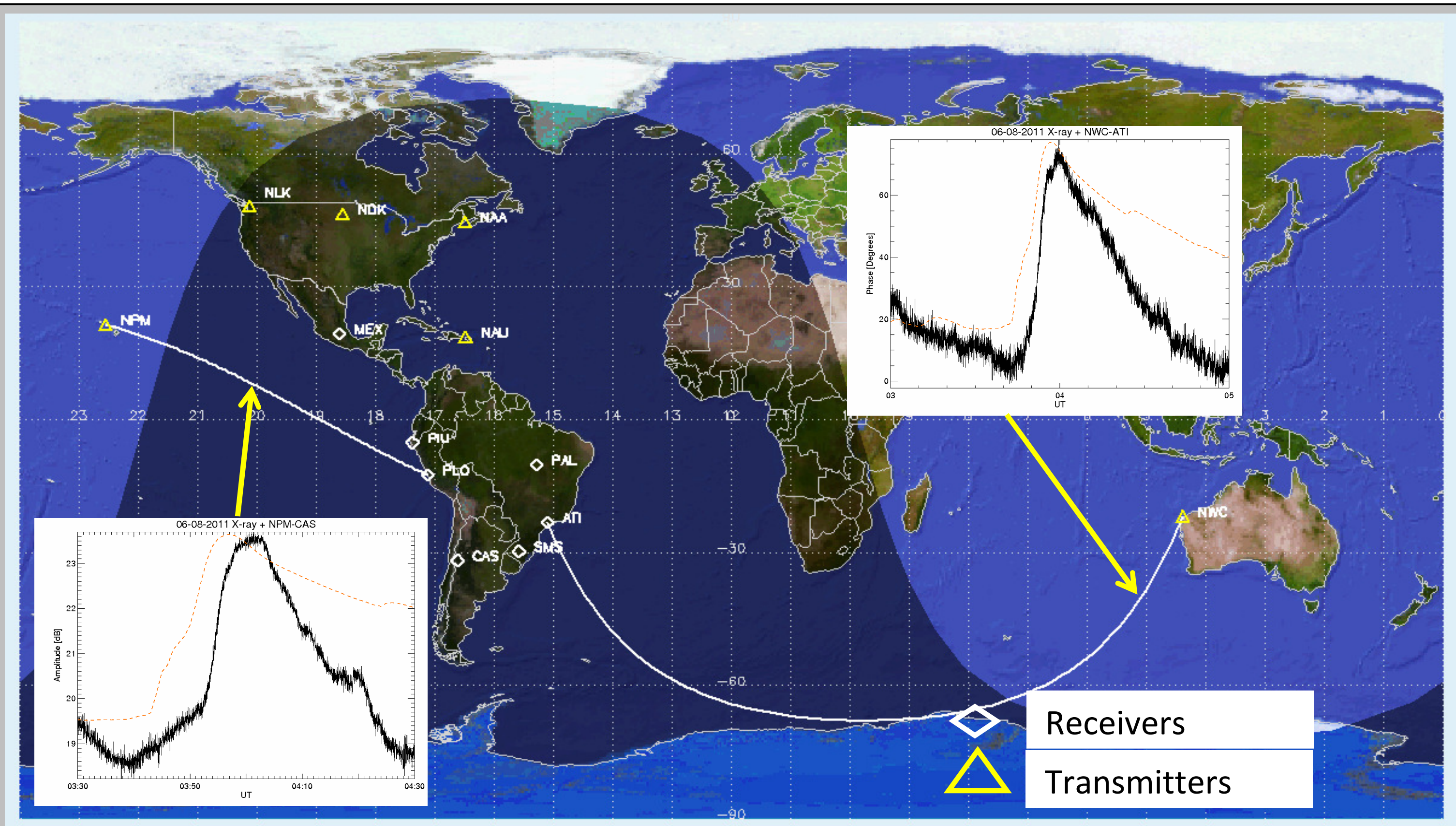
3rd ISWI Workshop – 8-12/10/2012 - Quito - Ecuador

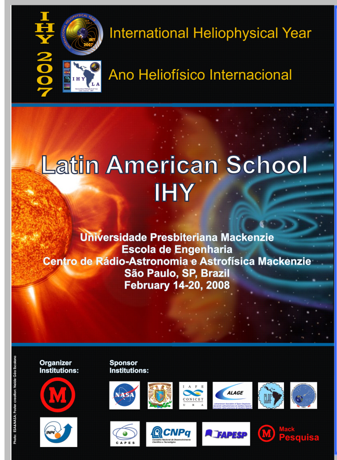
06-08-2011 Solar Flare

SAVNET (South America VLF NETwork) tracks **subionospheric propagation anomalies** of VLF waves emitted by powerful man-made transmitters Δ, and propagating in the **Earth-Ionosphere waveguide**. These anomalies are detected as **amplitude and phase variations** of the propagating waves. Anomalies are due to **varying electrical conductivity** of the boundary layers, due to **external disturbances** (transient and long-term solar variations, extra-terrestrial high-energy phenomena, precipitation of energetic particles, geomagnetic storms) or **internal forcing** from below (wave phenomena, lightning activity).



- 11 VLF tracking receiver stations deployed in Brazil, Peru, Argentina and Mexico.
- ~6 years of operation since 2007
- 3 new stations installed North of Brasil (06/12), and Quito (11/12)

SAVNET



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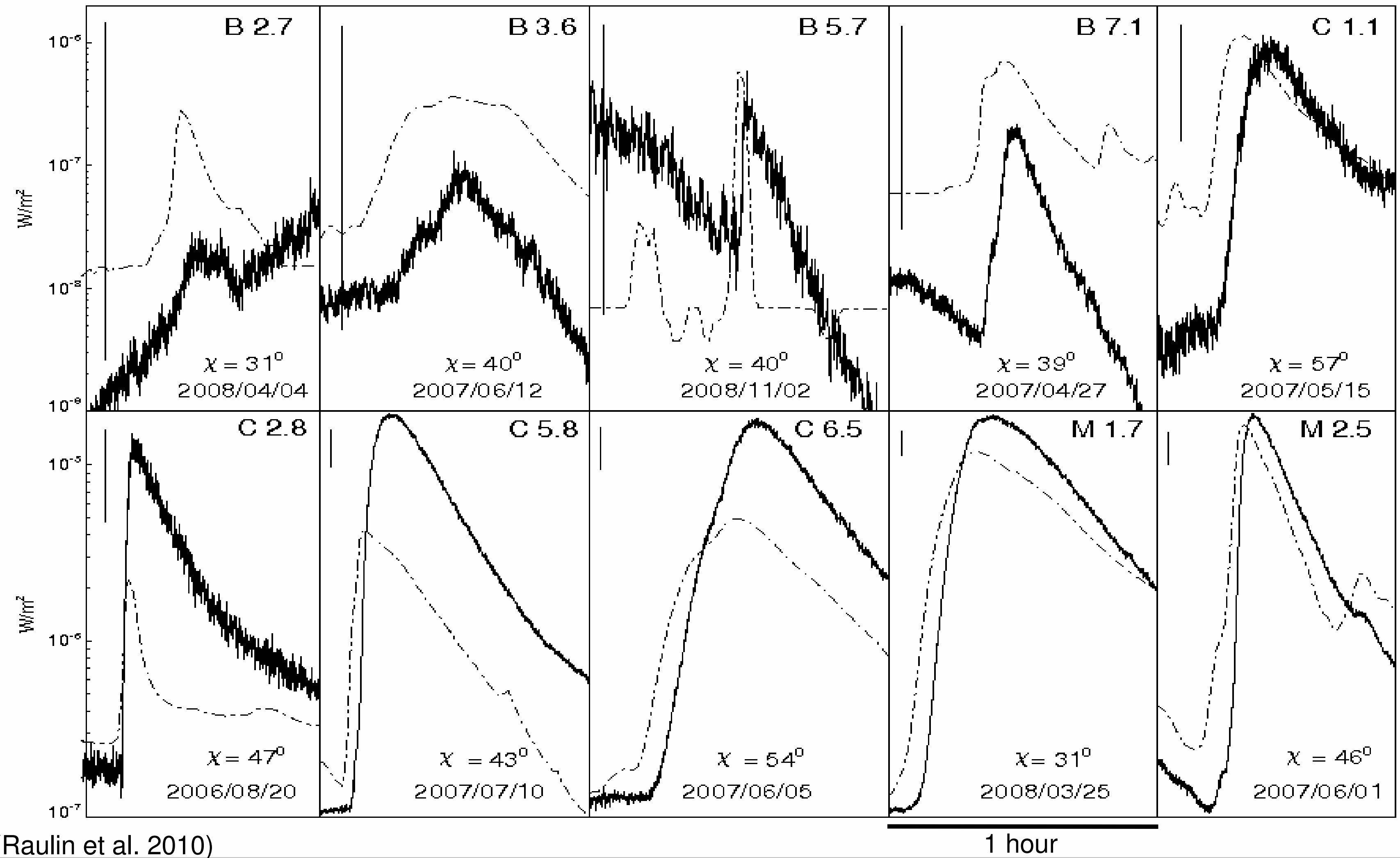
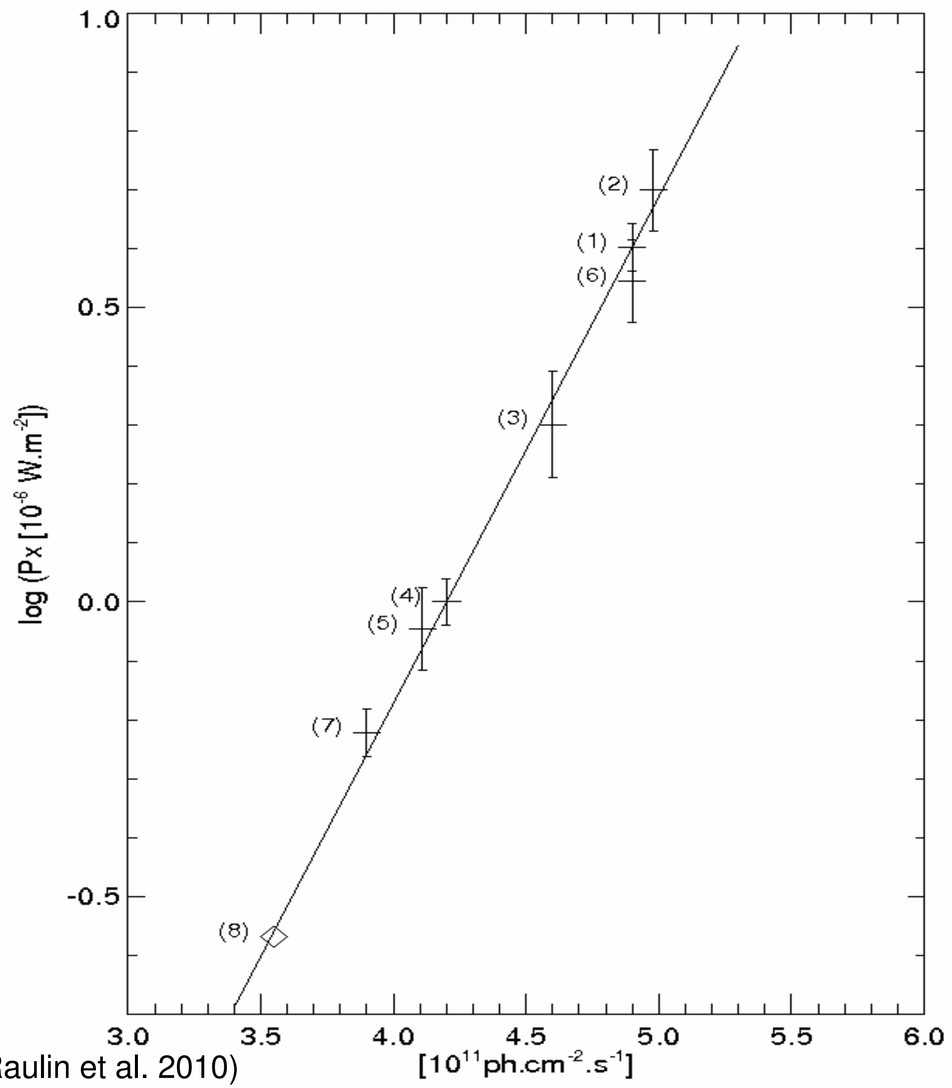
TRANSIENT SOLAR FORCING: FLARES

Lowest detected solar flare B 2.7 → 2.7 10^{-7} W/m^2 -- ≥ B 4 Class events are detected with 100 % probability



(Raulin et al. 2010)

TRANSIENT SOLAR FORCING: FLARES



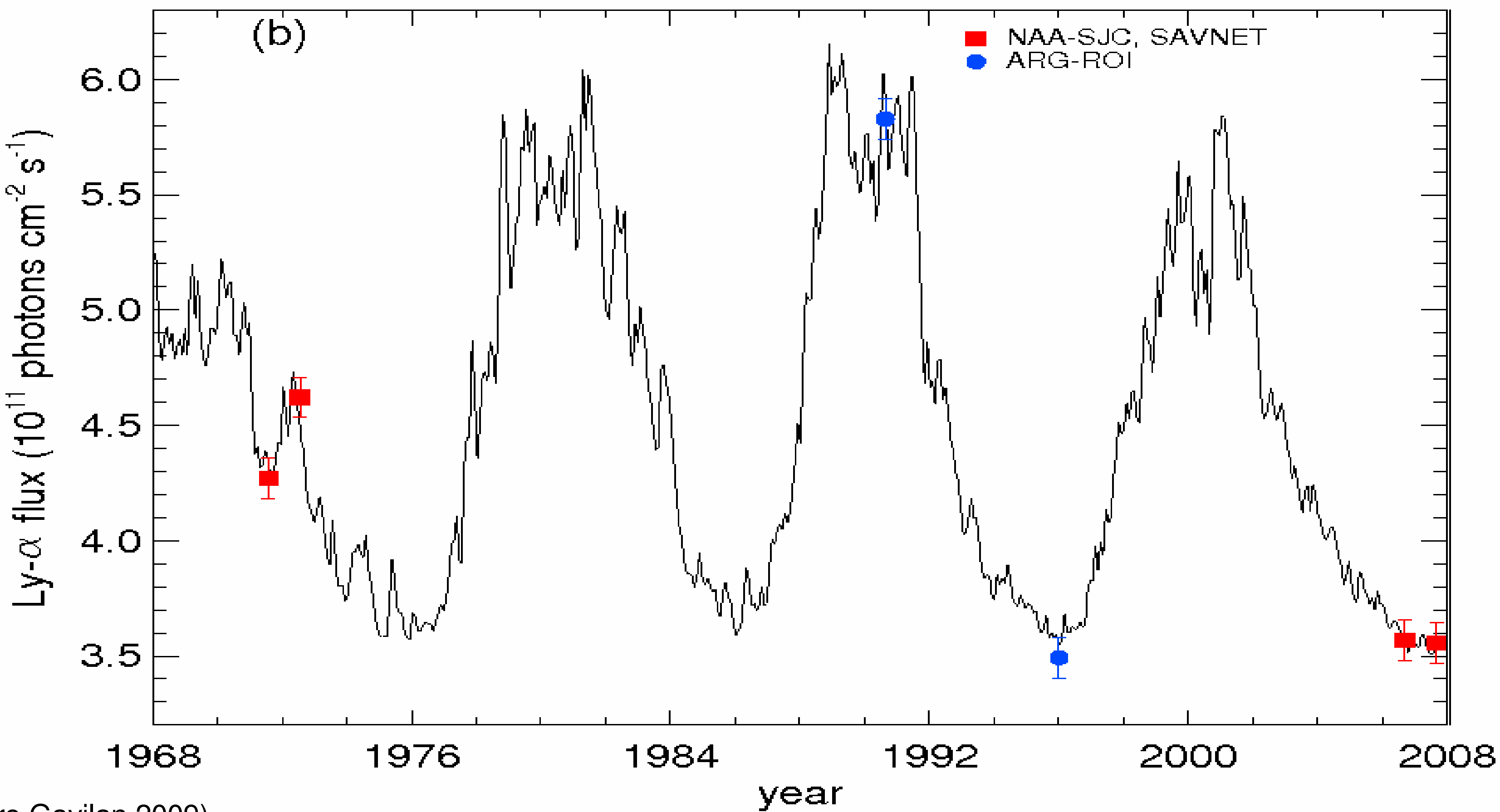
(Raulin et al. 2010)

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)

Phase changes during solar flares can be used to indirectly monitor the solar Lyman-α quiescent radiation

LONG-TERM SOLAR FORCING: C REGION



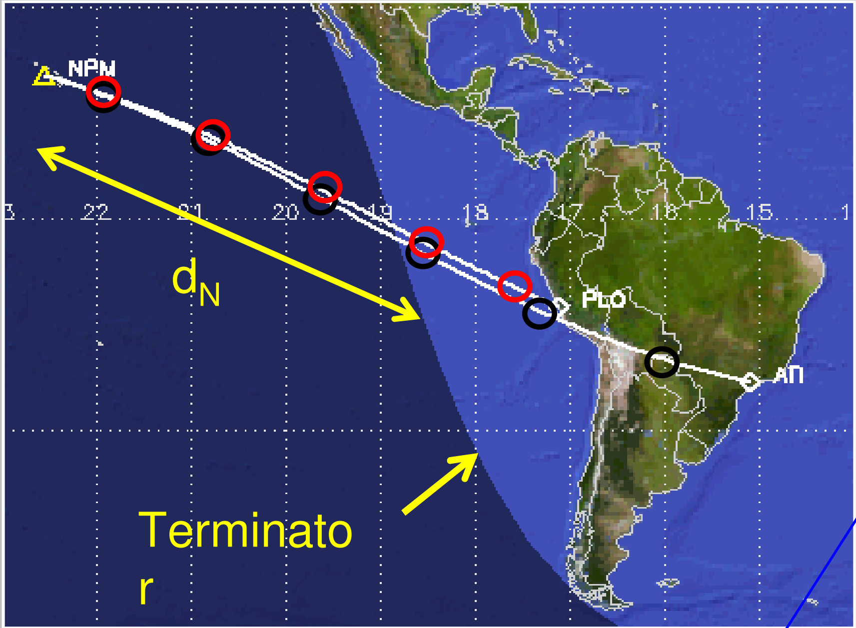
(Rivero Gavilan 2009)

Indirect solar Lyman-α monitoring using the VLF technique

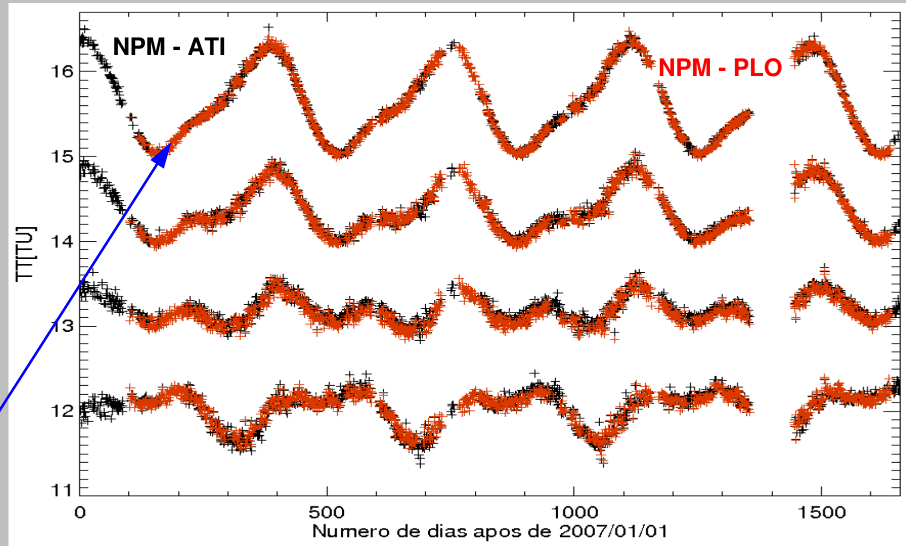
(Samanes 2010)

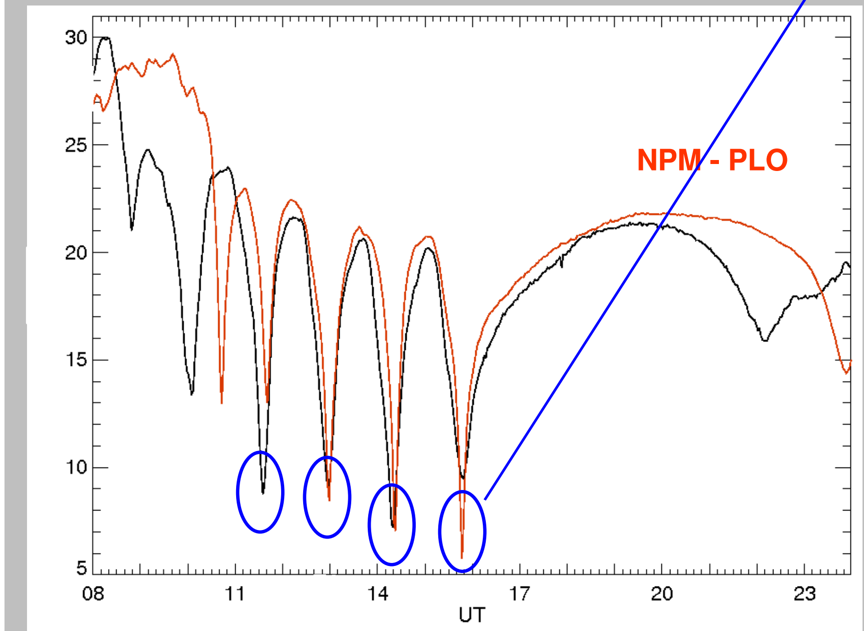
Terminator Time Method

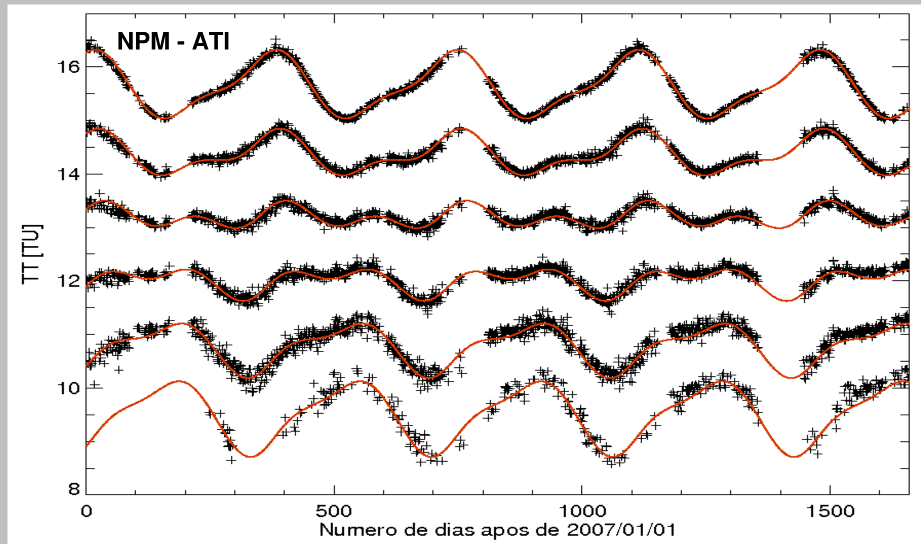
Search for Seismic-electromagnetic effects



Simultaneous Ttimes for ~ // VLF propagation paths



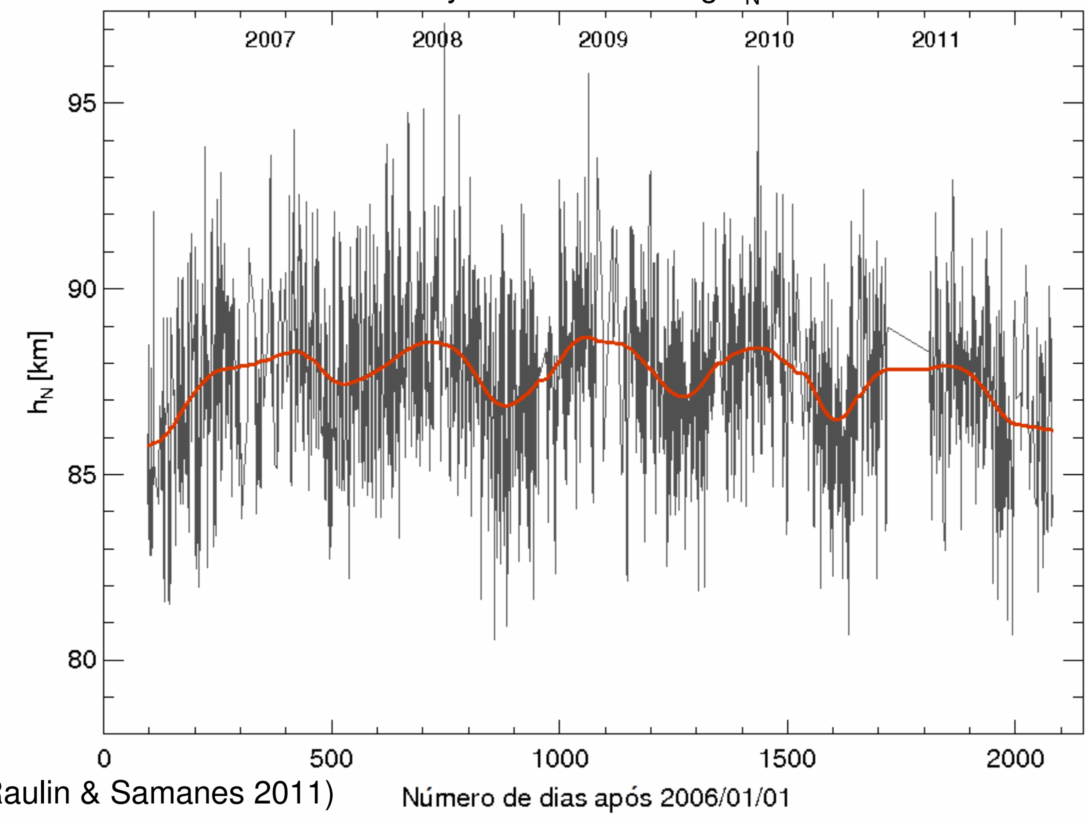




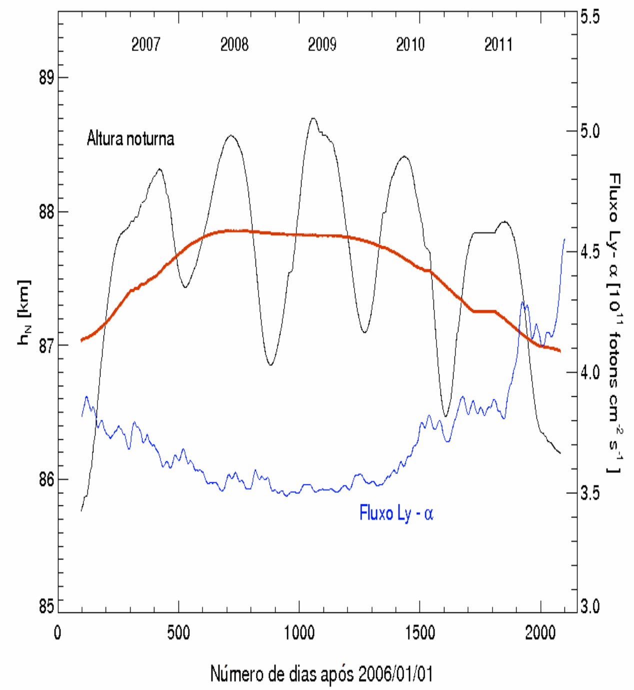
Terminator Time Method

Nighttime ionospheric height h_N

~ 6 years of monitoring h_N

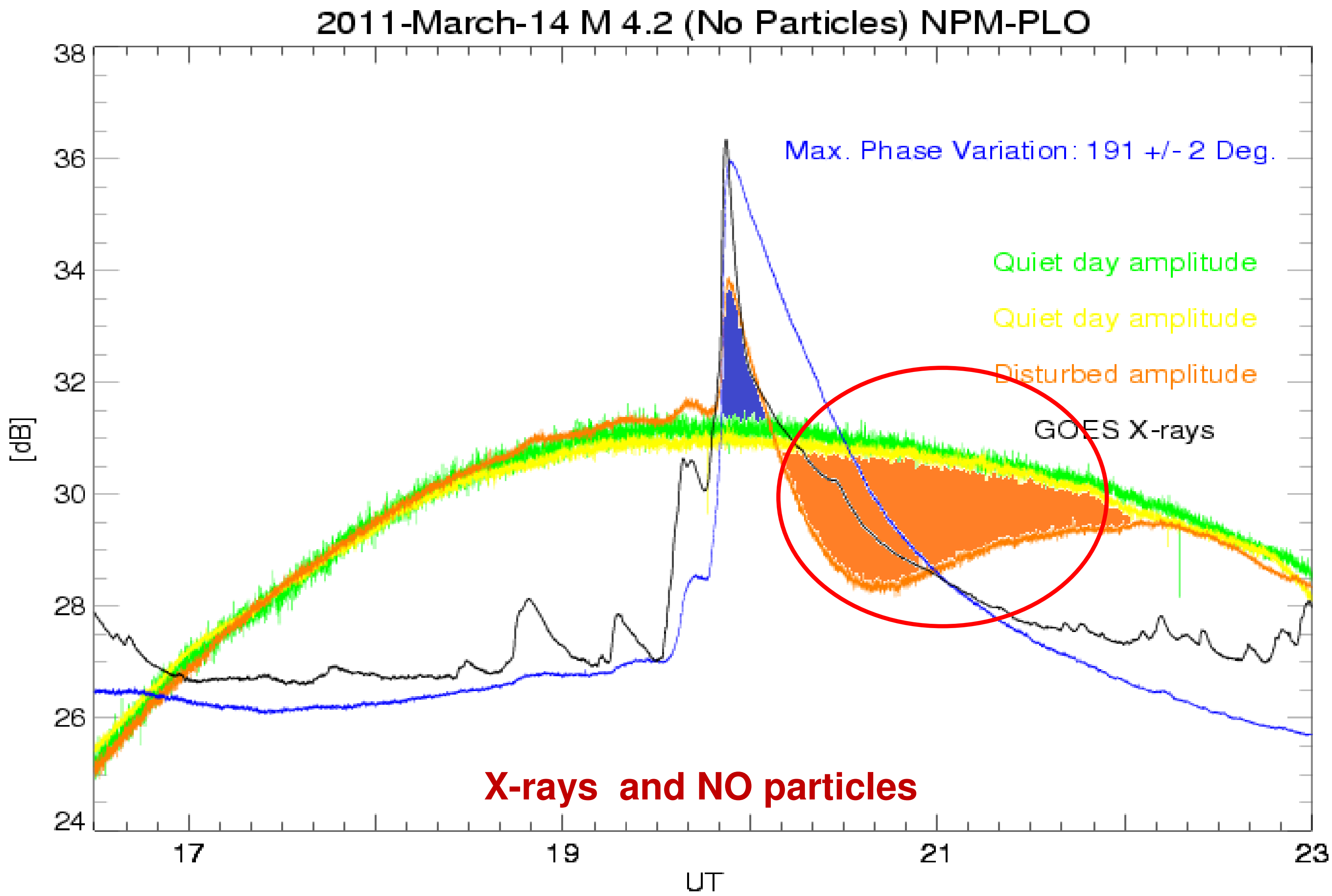


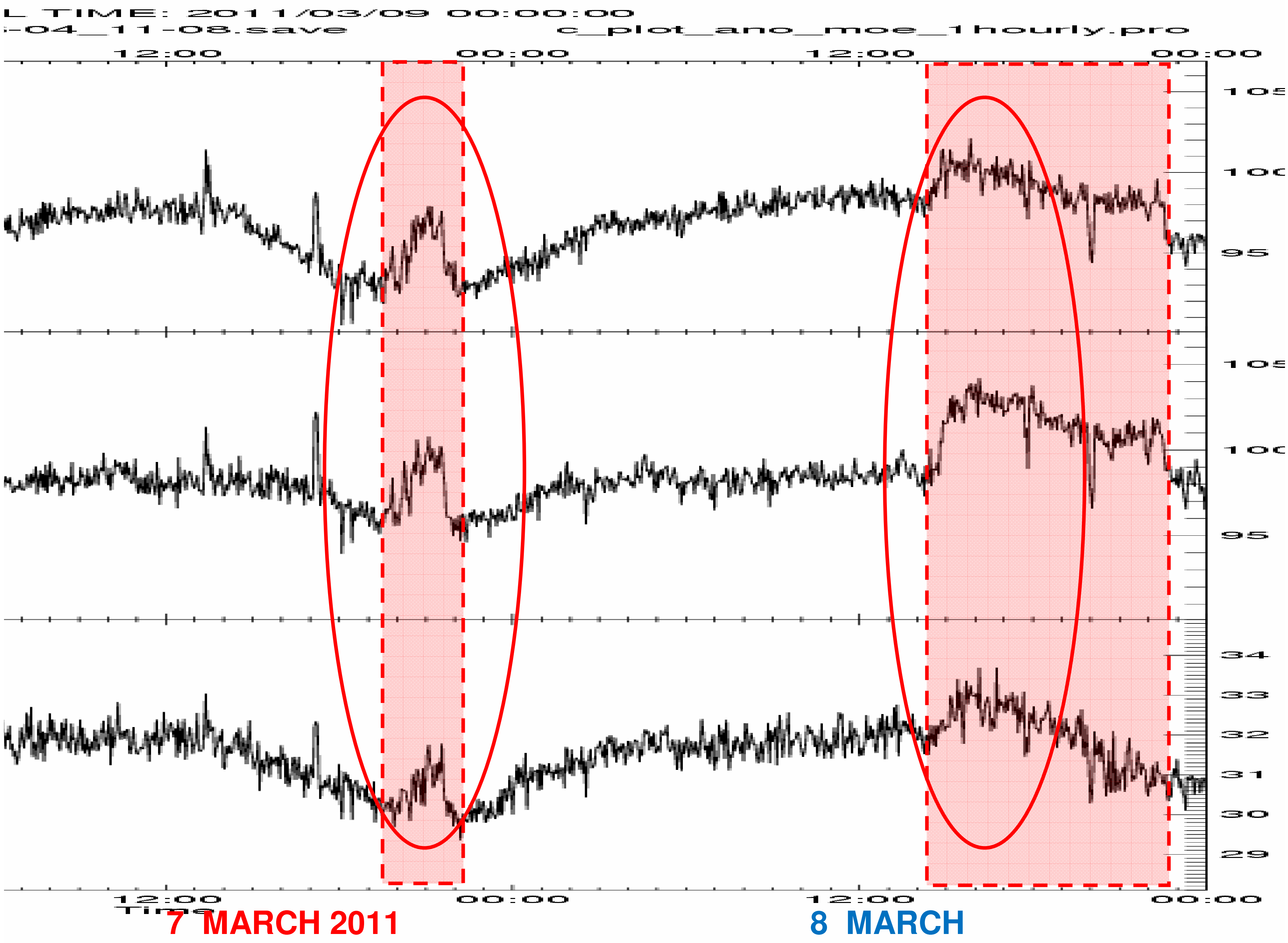
(Raulin & Samanes 2011)



- Clear seasonal variation → EM noise from lightning
- Long-term trend probably related to solar activity cycle

SOLAR PARTICLE EVENTS - SPE





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8 MARCH

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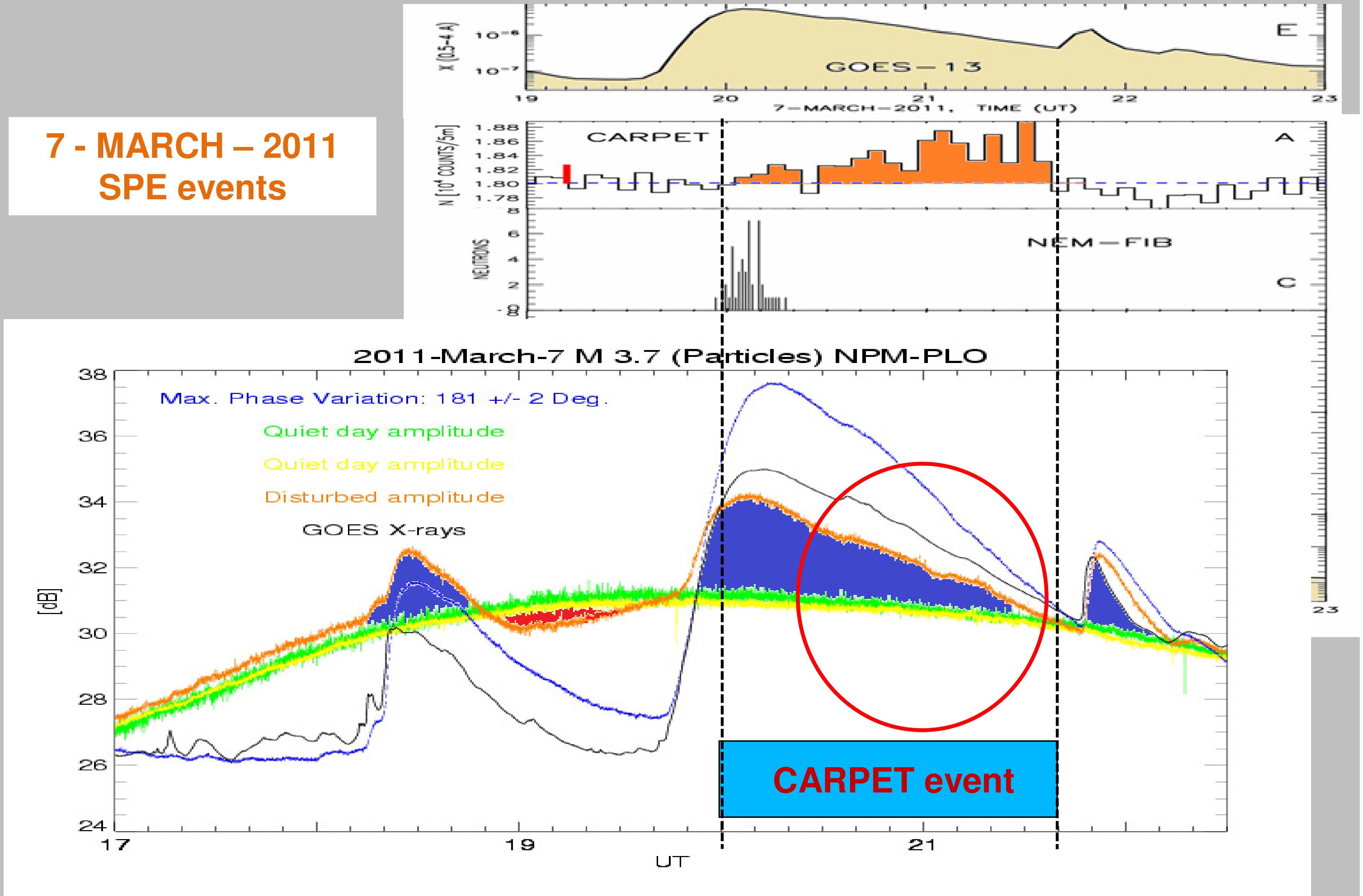
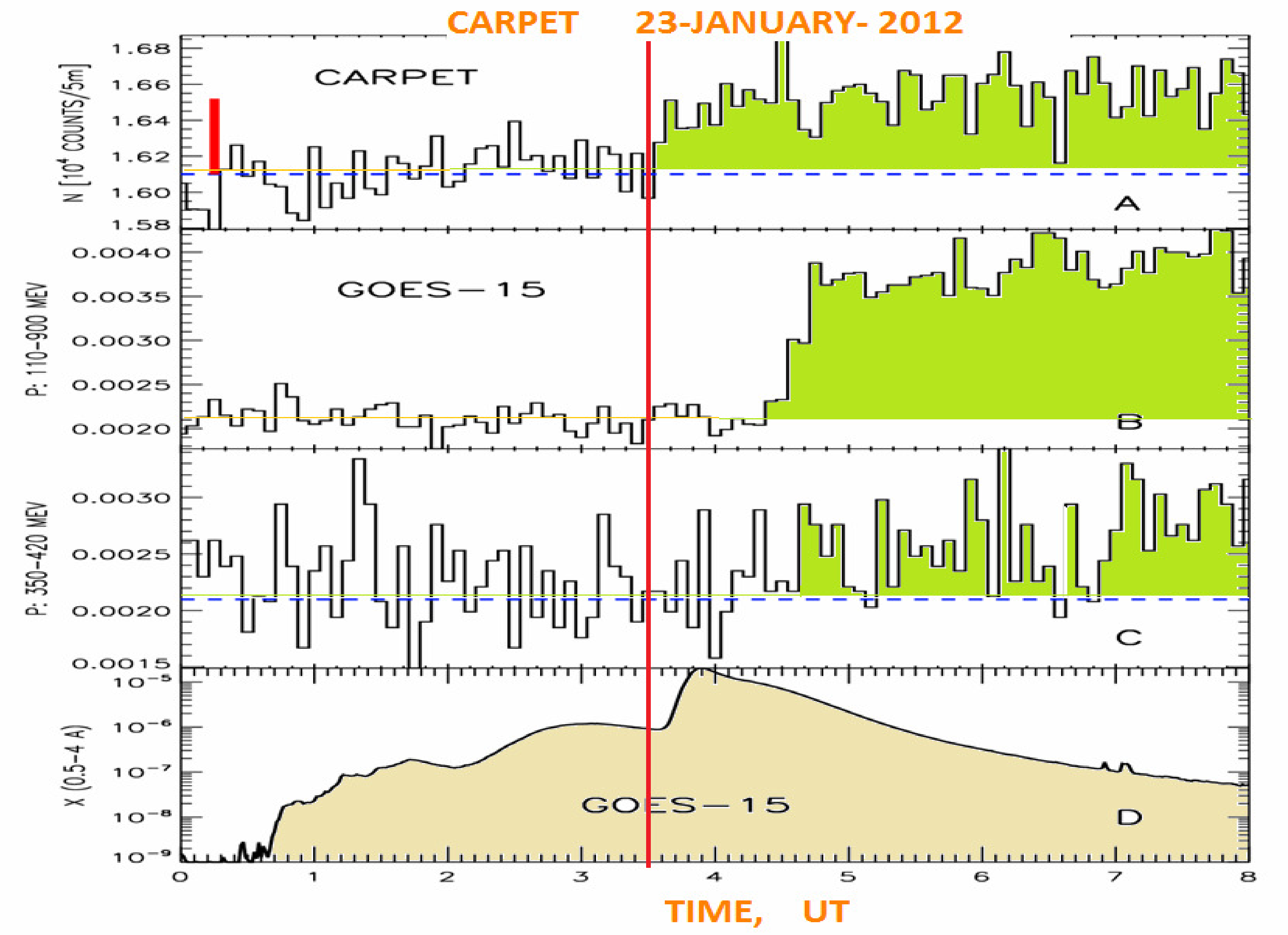
SPE events

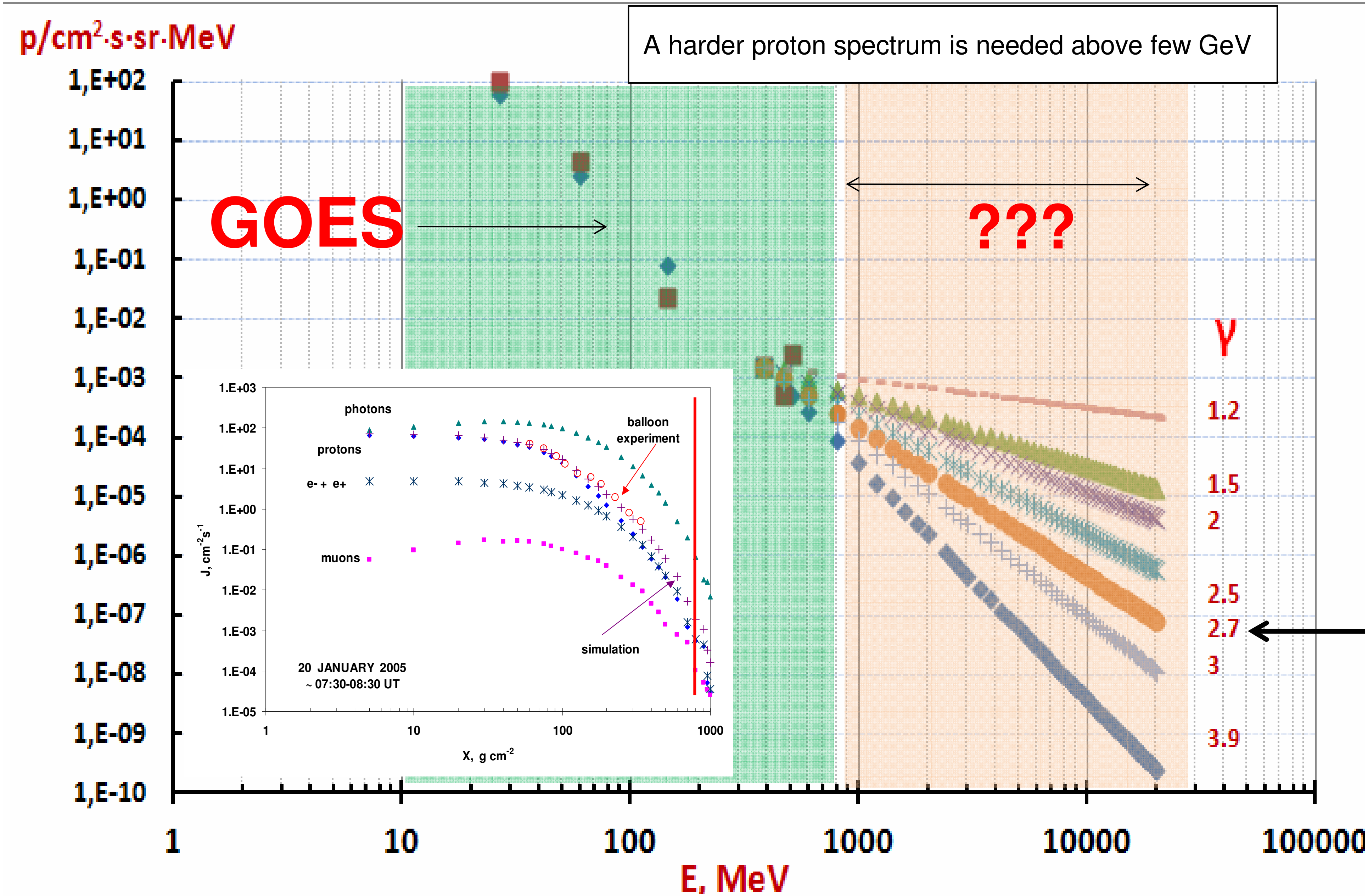


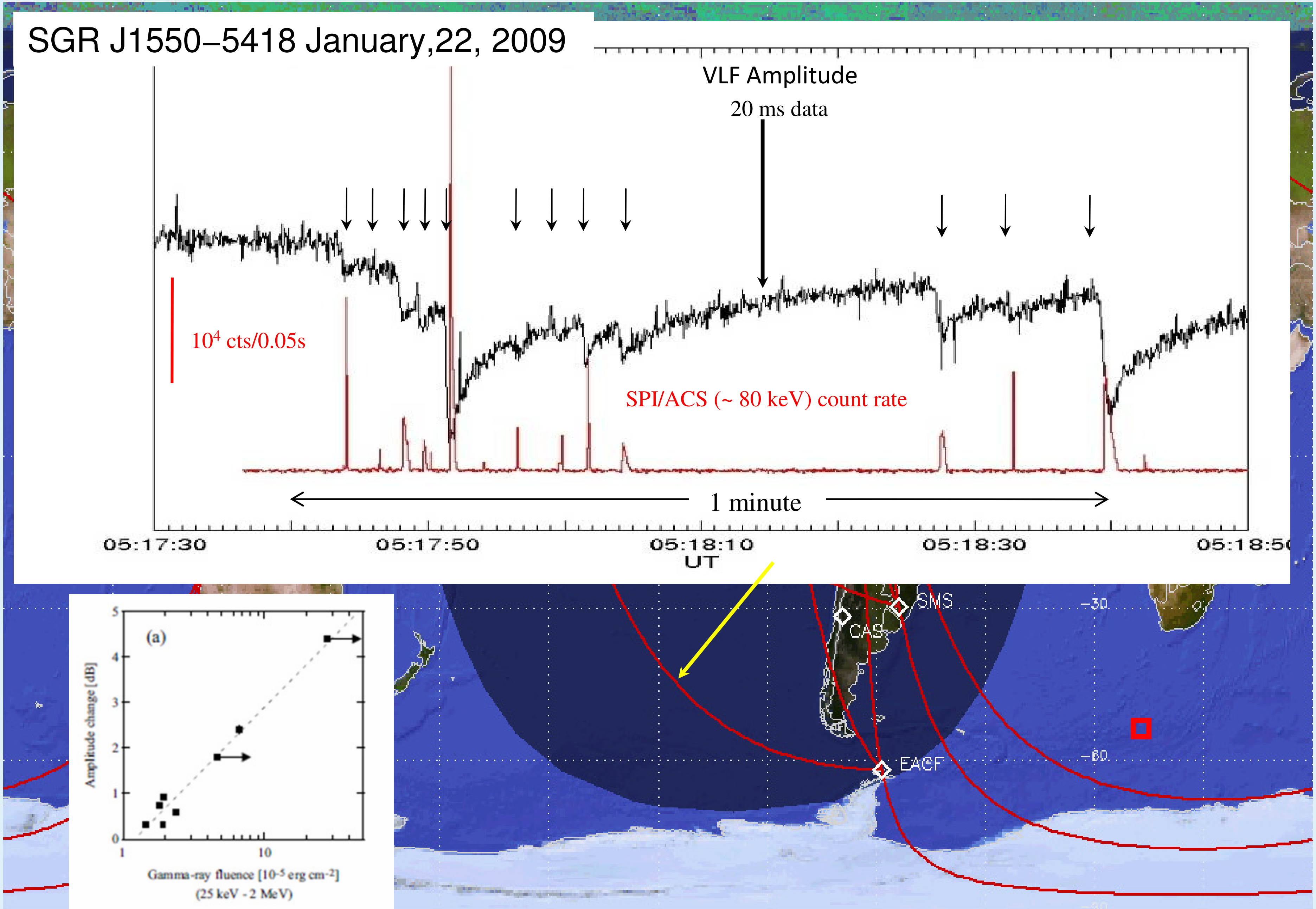
SOLAR PARTICLE EVENTS - SPE



Solar proton spectrum at the top of the Earth's atmosphere:

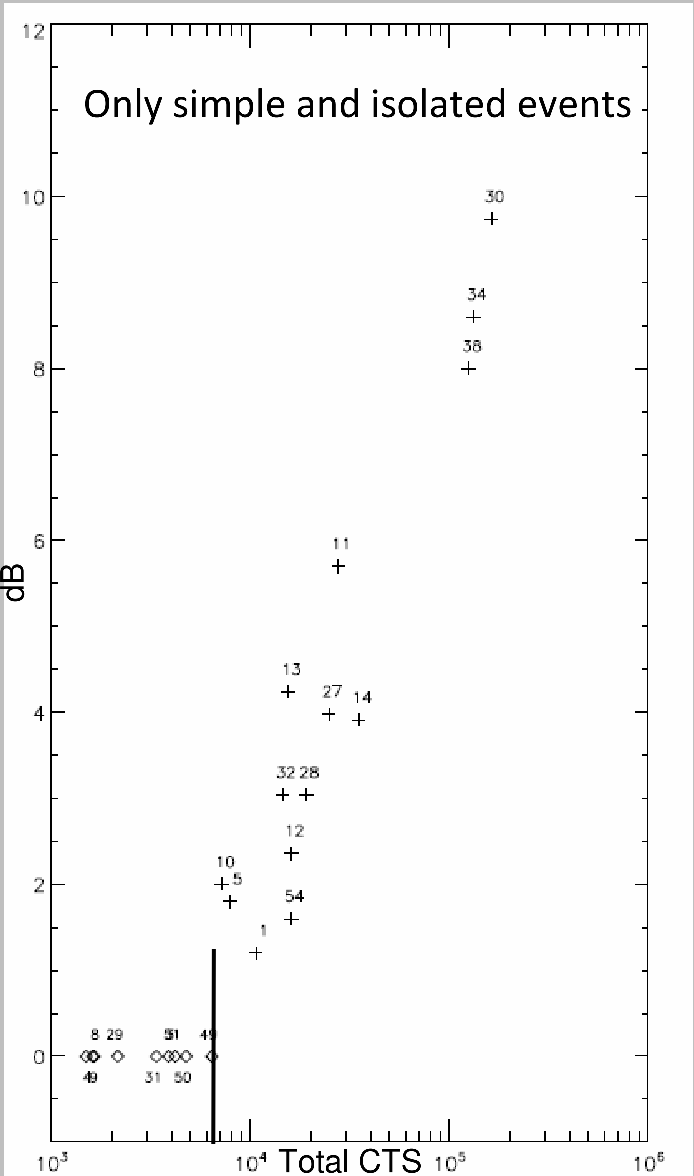
$J(E) = 3 \cdot 10^{7} \cdot E^{-3,9}$ p/(cm^2·s·sr·MeV)





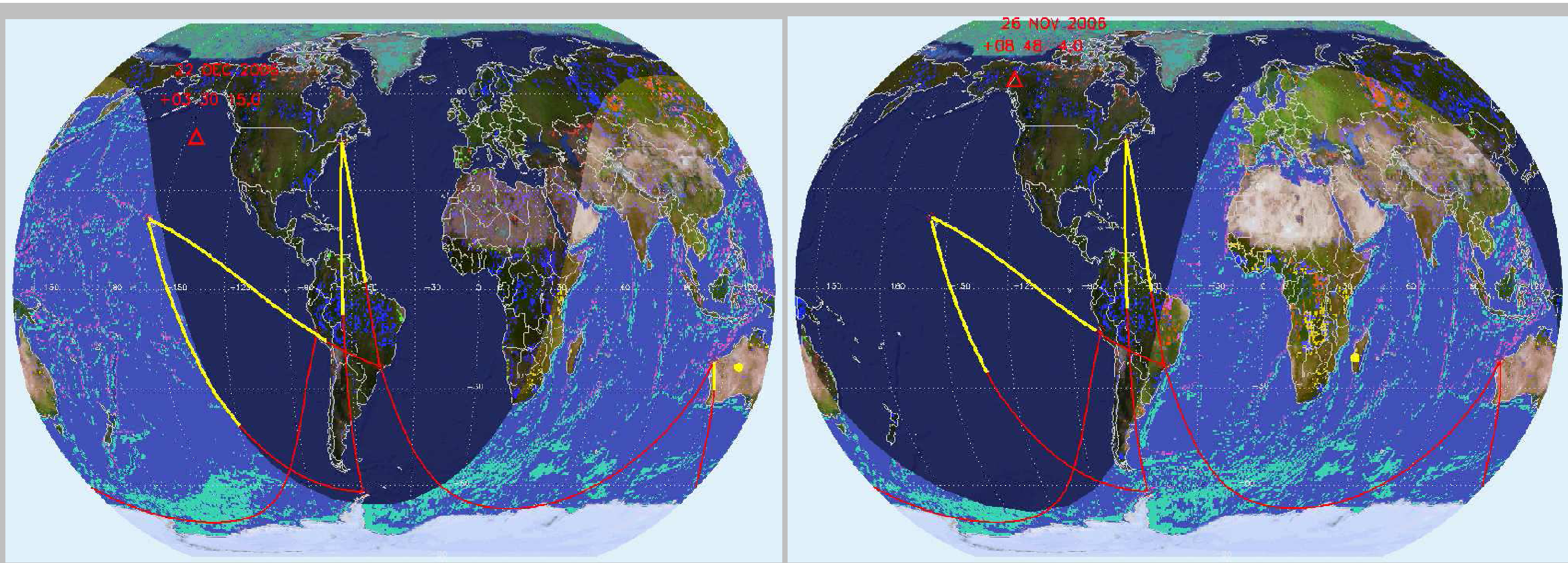
SGR J1550–5418 January,22, 2009
VLF Amplitude
20 ms data
10^4 cts/0.05s
SPI/ACS (~ 80 keV) count rate
1 minute
05:17:30
05:17:50
05:18:10
05:18:30
UT
SMS
CAS
EACF
-30
-60
(a)
Amplitude change [dB]
Gamma-ray fluence [10-5 erg cm-2]
(25 keV - 2 MeV)

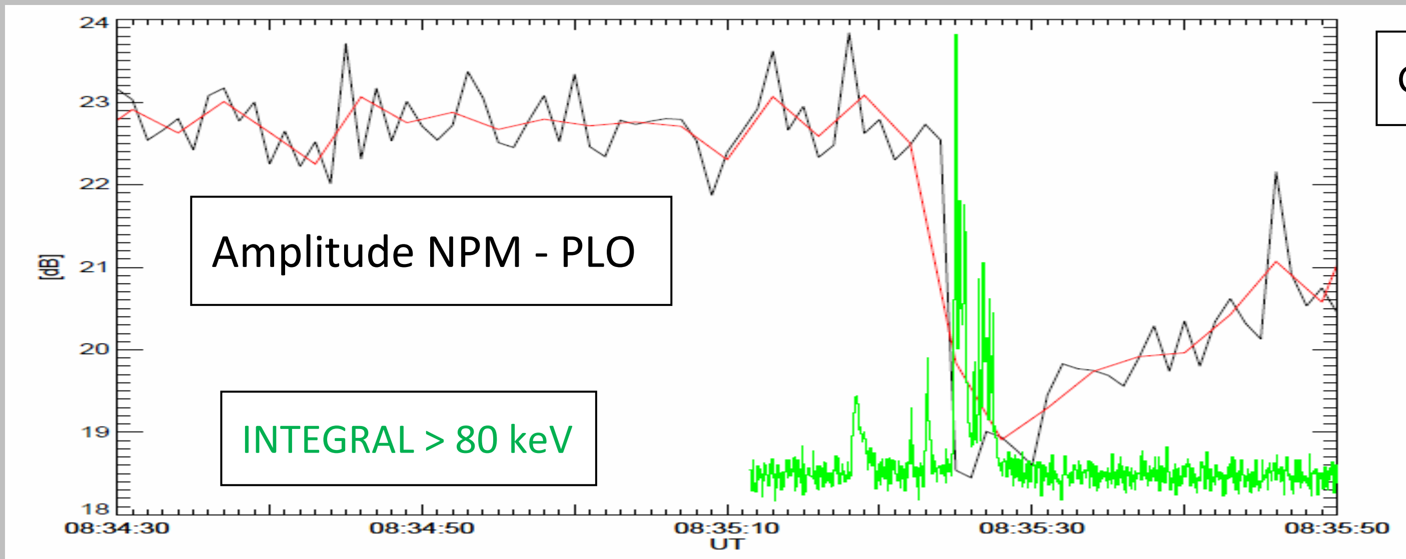
SGR J1550–5418 January,22, 2009



The amplitude and phase variations for intermediate-to-low gamma-ray bursts on 22 January 2009, are well correlated with the photon (> 80 keV) total counts. This correlation can be used to infer the γ-rays for **non-detected** (from space because of Earth occultation or saturation or off-pointing) high-energy phenomena. The VLF technique offers the possibility of 24-hours sky monitoring .

Automatic search for good GRB candidates in RHESSI, FERMI, INTEGRAL, SWIFT, SUZAKU





GRB 090401B

SUMMARY

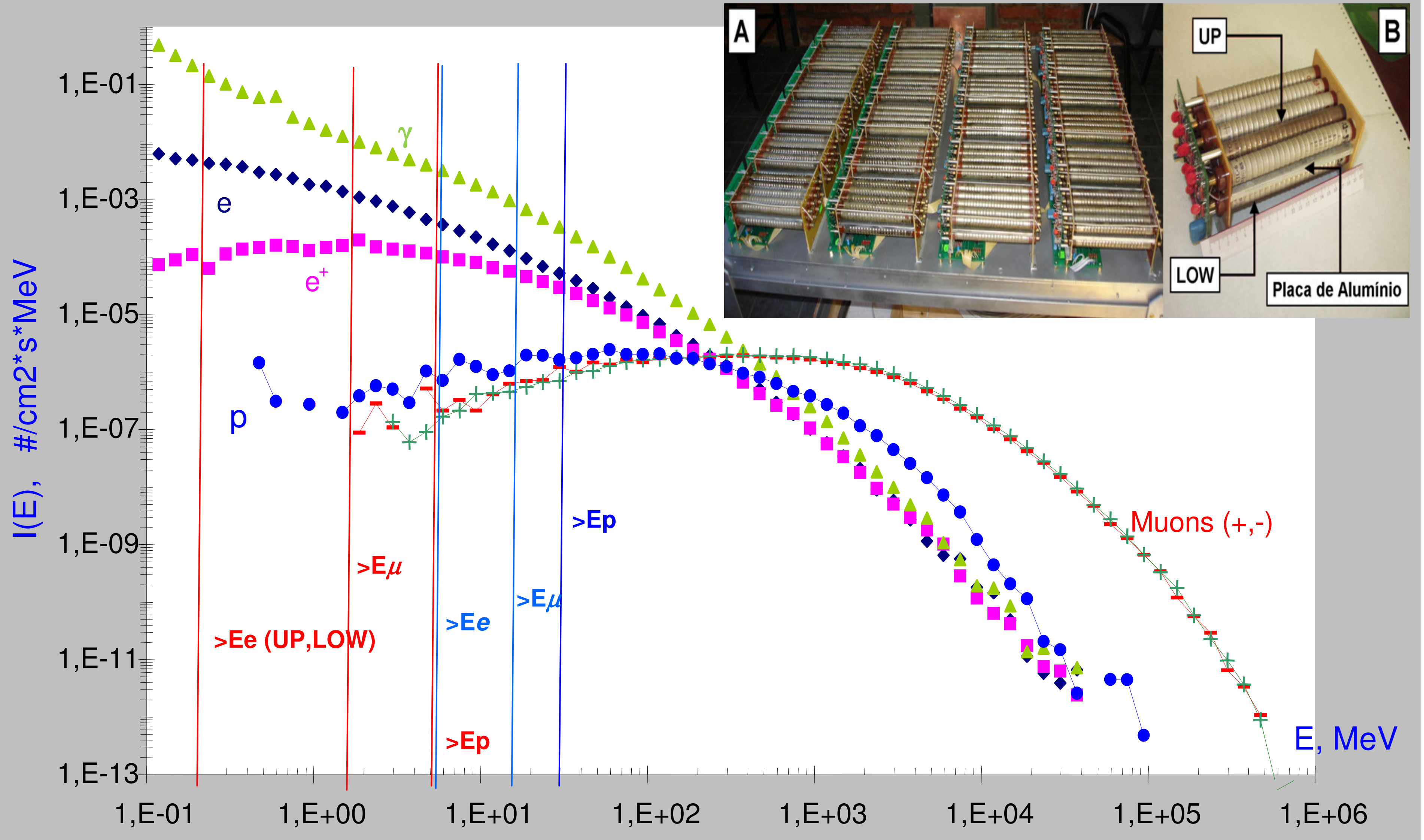
The very simple VLF technique of remote sensing of the low ionosphere has shown to be able to diagnose many aspects of Space Weather phenomena, including disturbances from remote objects of great astrophysical importance.

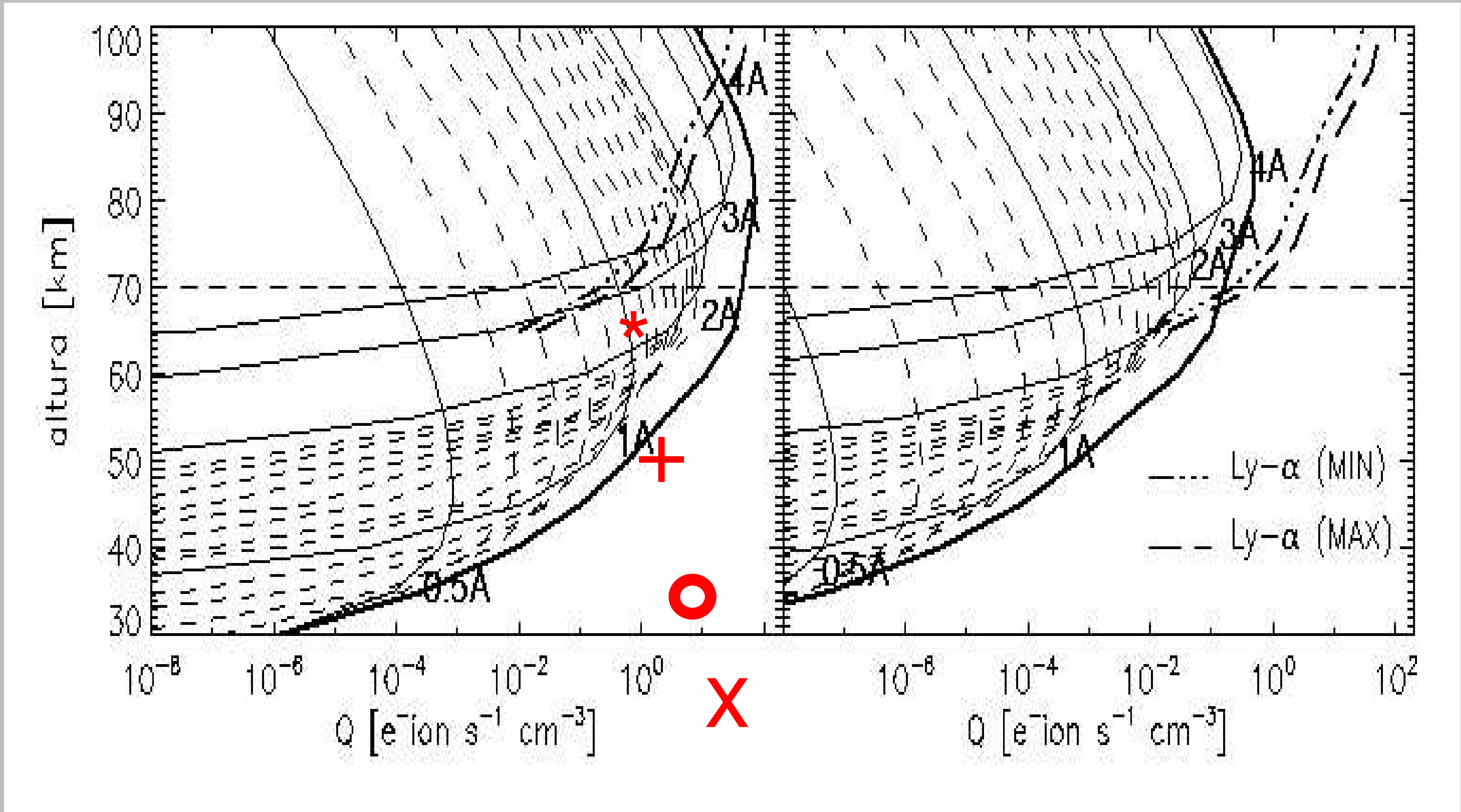
The lower ionosphere plasma is a very sensitive medium to external and internal forcing: radiation, energetic particle fluxes, atmospheric variability.

The timescales involved give new insights on the monitoring of the long-term and transient solar activities, the episodic geomagnetic disturbances, energetic particle events, and upper propagating phenomena in the neutral atmosphere.

Differential Energy spectra of CR secondaries p, e^-, e^+, μ^+, μ^- and γ at atmospheric depth X=800 g·cm^{-2}

UP, LOW : e> 0,2 MeV, p> 5 MeV, γ>0,02 MeV, μ>1,5 MeV TEL: e> 5 Mev, p > 30 MeV, μ> 15.5 MeV





* 1 proton at 10 MeV (1000 p/cm²/s/sr)

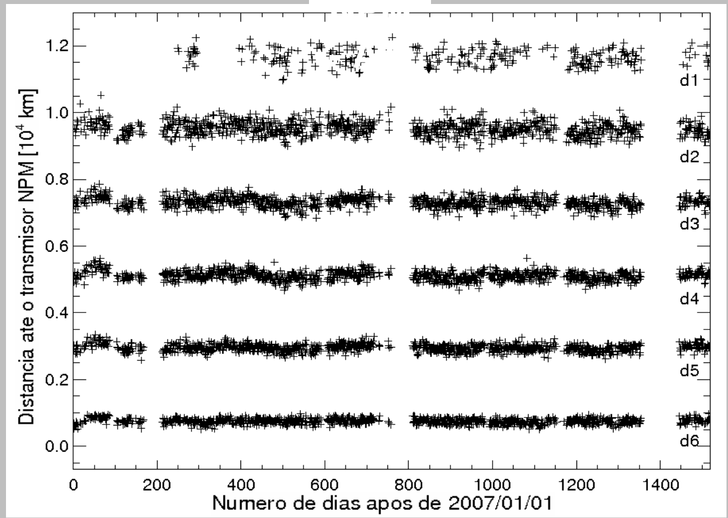
+ 1 proton at 30 MeV (100 p/cm²/s/sr)

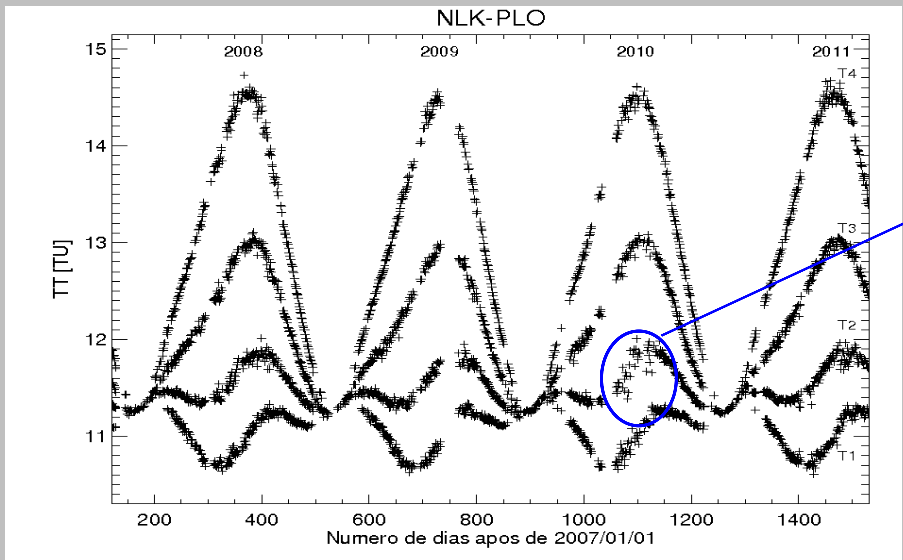
o 1 proton at 100 MeV (0.1 p/cm²/s/sr)

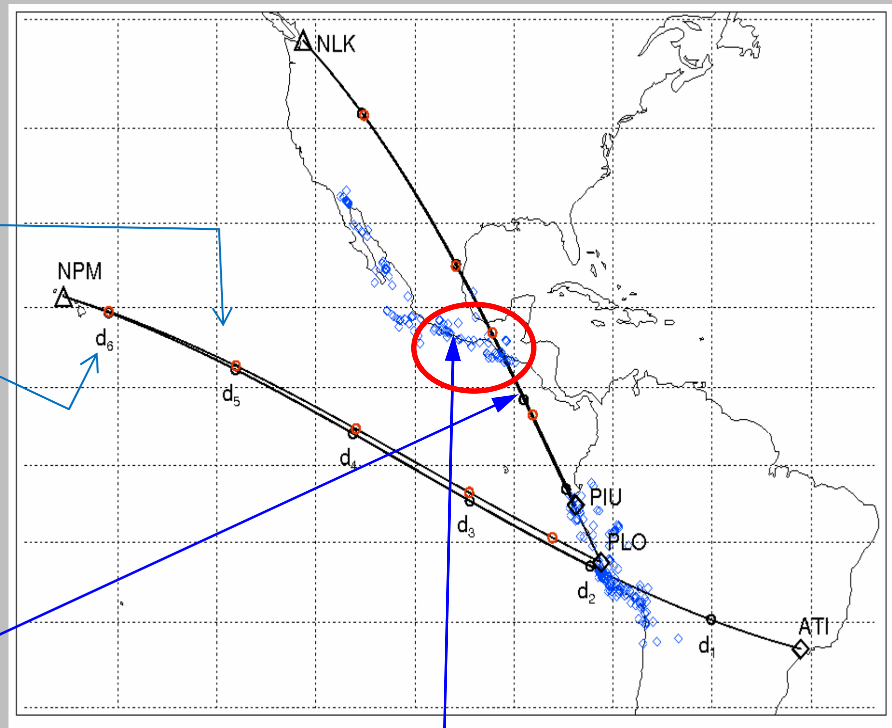
X 1 proton at 1 GeV (0.00005 p/cm²/s/sr)

Search for Seismic-electromagnetic effects

Samanes & Raulin, 2011







M = 5.9,5.8,5.6,6.5,5.1

Depth = 15,10, 5, 8, 8 km

October-November 2009