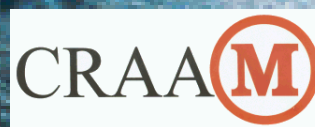




The South America VLF Network - SAVNET: Achievements, latest results and future directions

Jean-Pierre Raulin



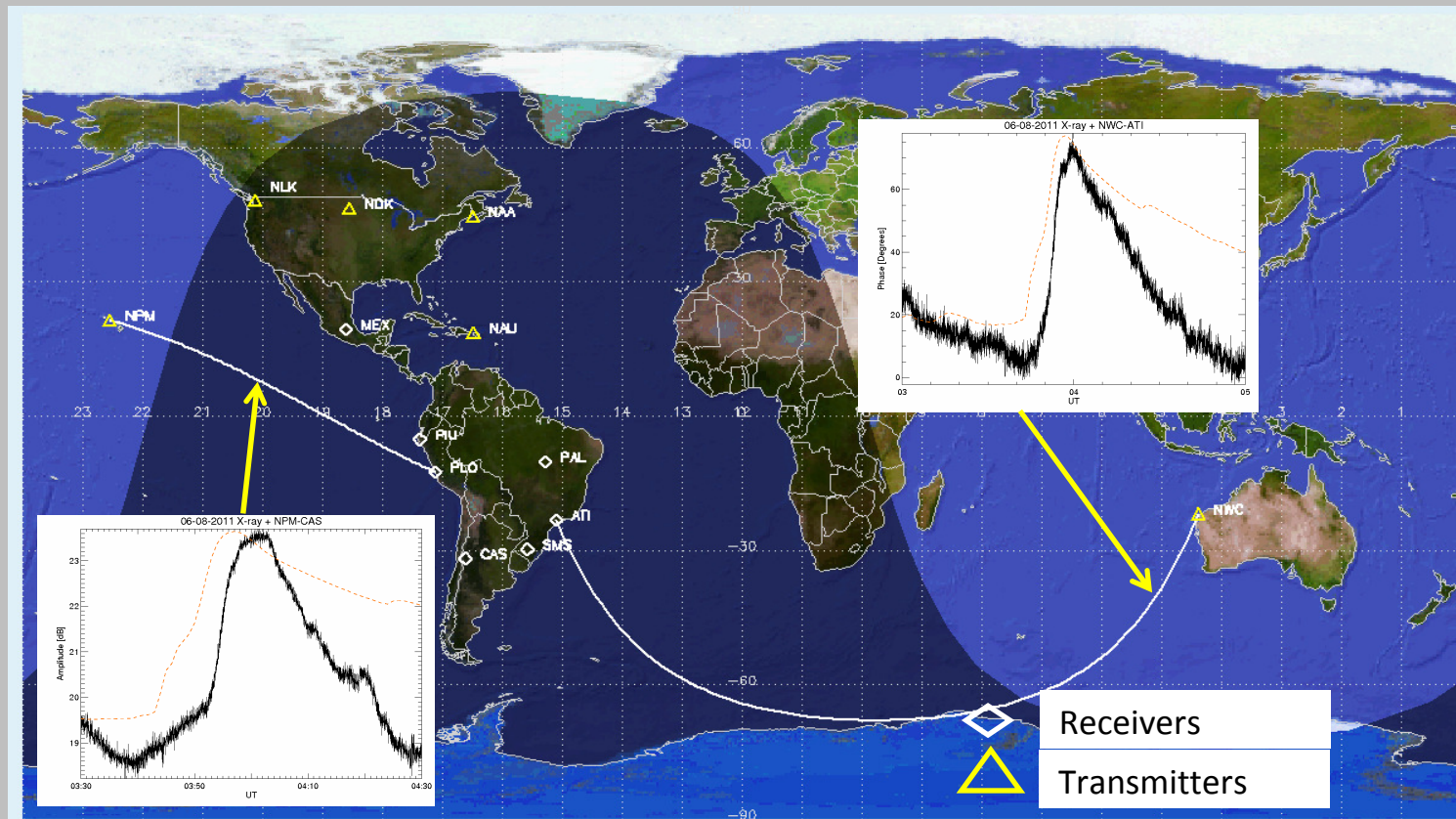
*Centro de Radioastronomia e Astrofísica Mackenzie, Universidade
Presbiteriana Mackenzie, Escola de Engenharia, São Paulo, SP, Brazil*

*H. Rivero Gavilan, J. Samanes, E. Macotela, R. Escate, G. Trottet, A. Pacini, F. Bertoni, E.
Correia, P. Kaufmann*

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



International Heliophysical Year
Ano Heliofísico Internacional

Latin American School
IHY

Universidade Presbiteriana Mackenzie
Escola de Engenharia
Centro de Rádio-Astronomia e Astrofísica Mackenzie
São Paulo, SP, Brazil
February 14-20, 2008

CURSO-TALLER
Conexión Sol-Tierra
Del 17 al 22 de Abril del 2006

Dr. Jean Pierre Raulin
Investigador del CNRS (Centro Nacional de Investigación Científica y Tecnológica) del CNRS (Centre National de la Recherche Scientifique) del CNRS (Centre National de la Recherche Scientifique)

Dirigido a estudiantes universitarios de Ciencias (pre y post grado), investigadores y público en general con conocimientos de física.

CONTENIDO

- El Sol y su ciclo de actividad
- La conexión Sol-Tierra
- Aspectos de la dinámica del Clima Espacial sobre la Atmósfera Terrestre y Sistemas Tecnológicos
- La ionosfera terrestre como un enorme sensor de señales solares.

HORARIO: Lunes a Viernes de 3 a 5 p.m.
Sábado de 8 a 11 a.m.

LOCAL: Lunes, Martes, Miércoles - Auditorio Fac. Física U.N.M.S.M. Av. Venezuela Cdra. 34 Ciudad Universitaria Juanes, Vicos y Sábado - Auditorio CONIDA Jr. Luis Felipe Villarín 1060, San Isidro

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Red de VLF de América del Sur
(SAVNET): estudios de la actividad solar, geofísica y astronómica para aplicaciones científicas y tecnológicas

Jean-Pierre Raulin
CRAAM-EE-Mackenzie

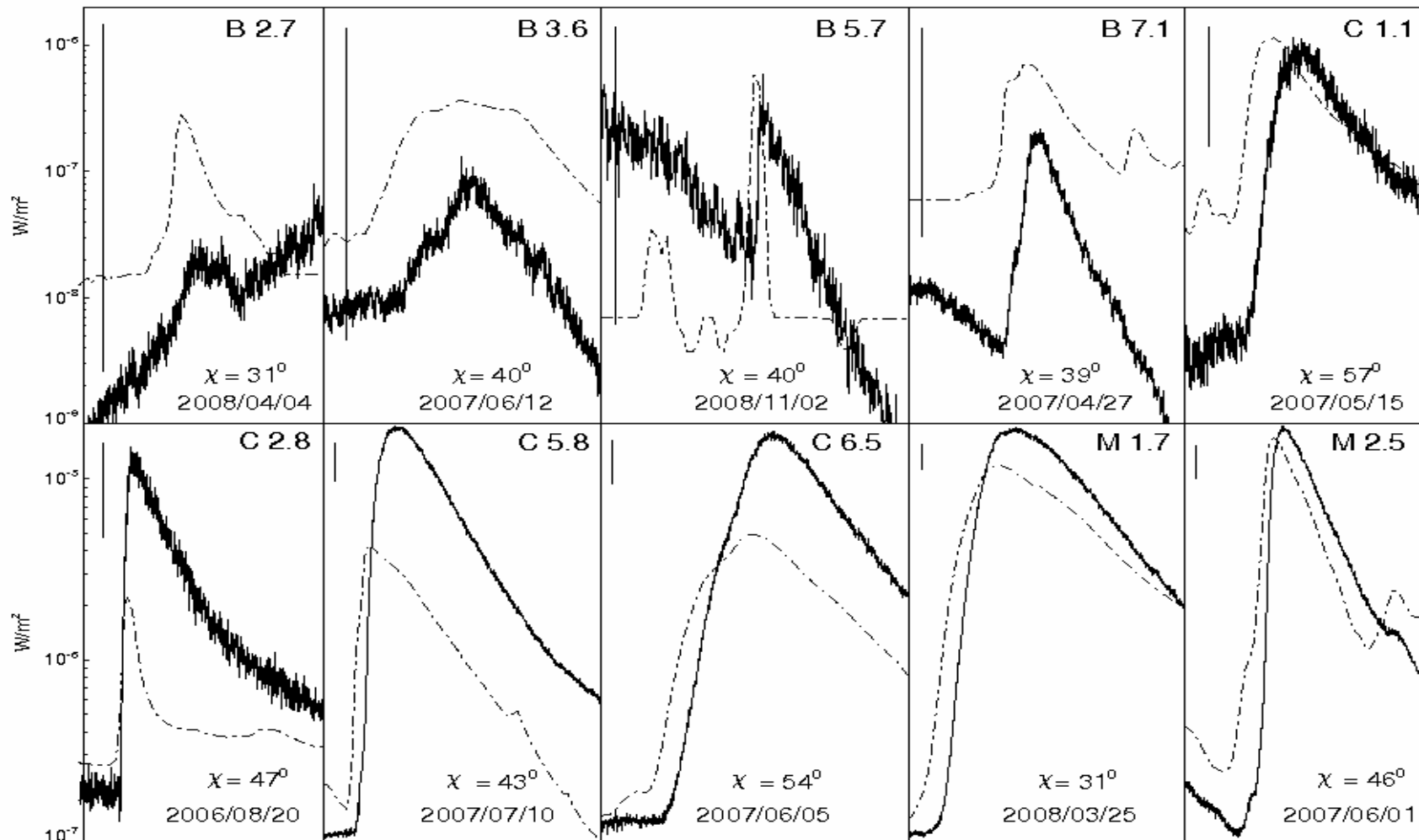
LIMA, ICA, April, 2009



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

TRANSIENT SOLAR FORCING: FLARES

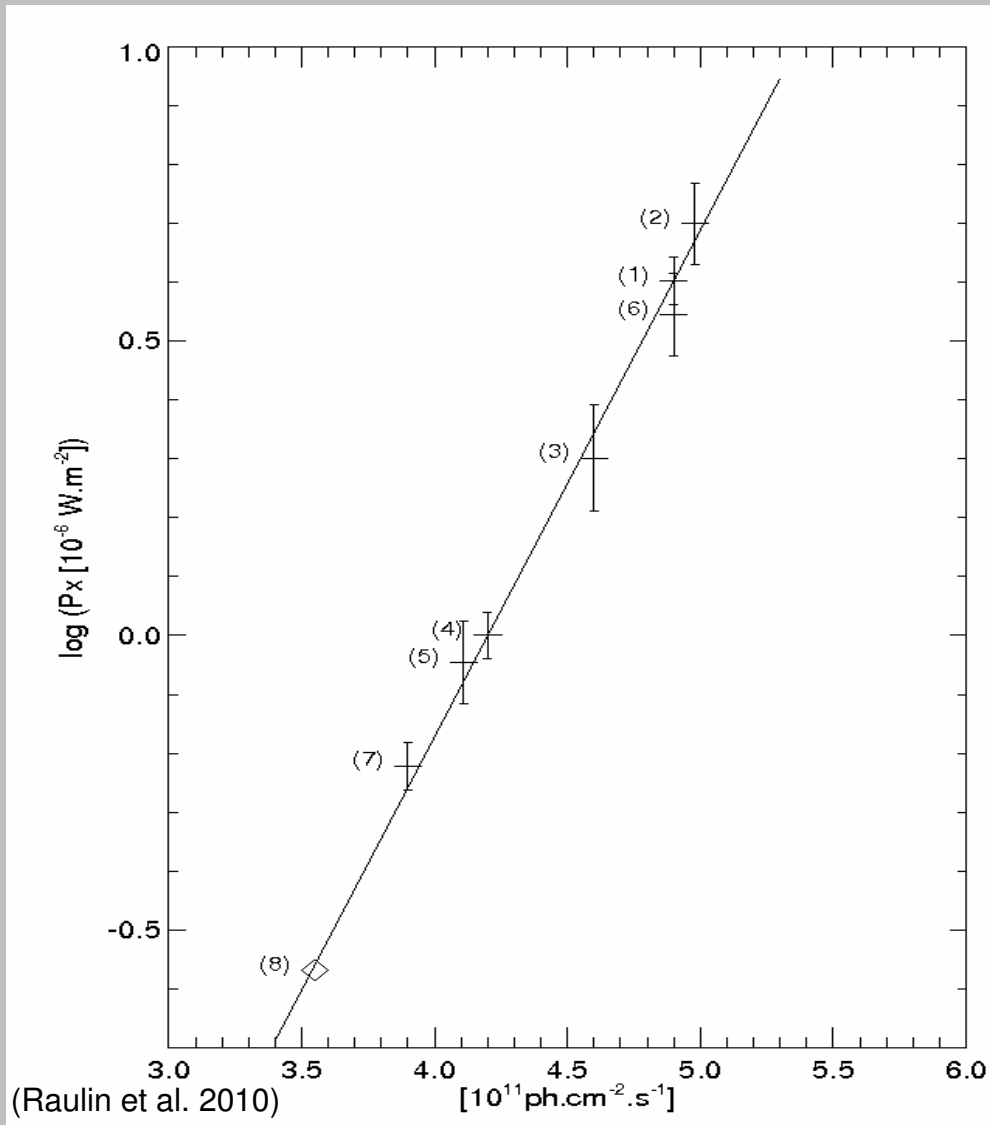
Lowest detected solar flare B 2.7 \rightarrow $2.7 \cdot 10^{-7} \text{ W/m}^2$ -- \geq B 4 Class events are detected with 100 % probability



(Raulin et al. 2010)

1 hour

TRANSIENT SOLAR FORCING: FLARES



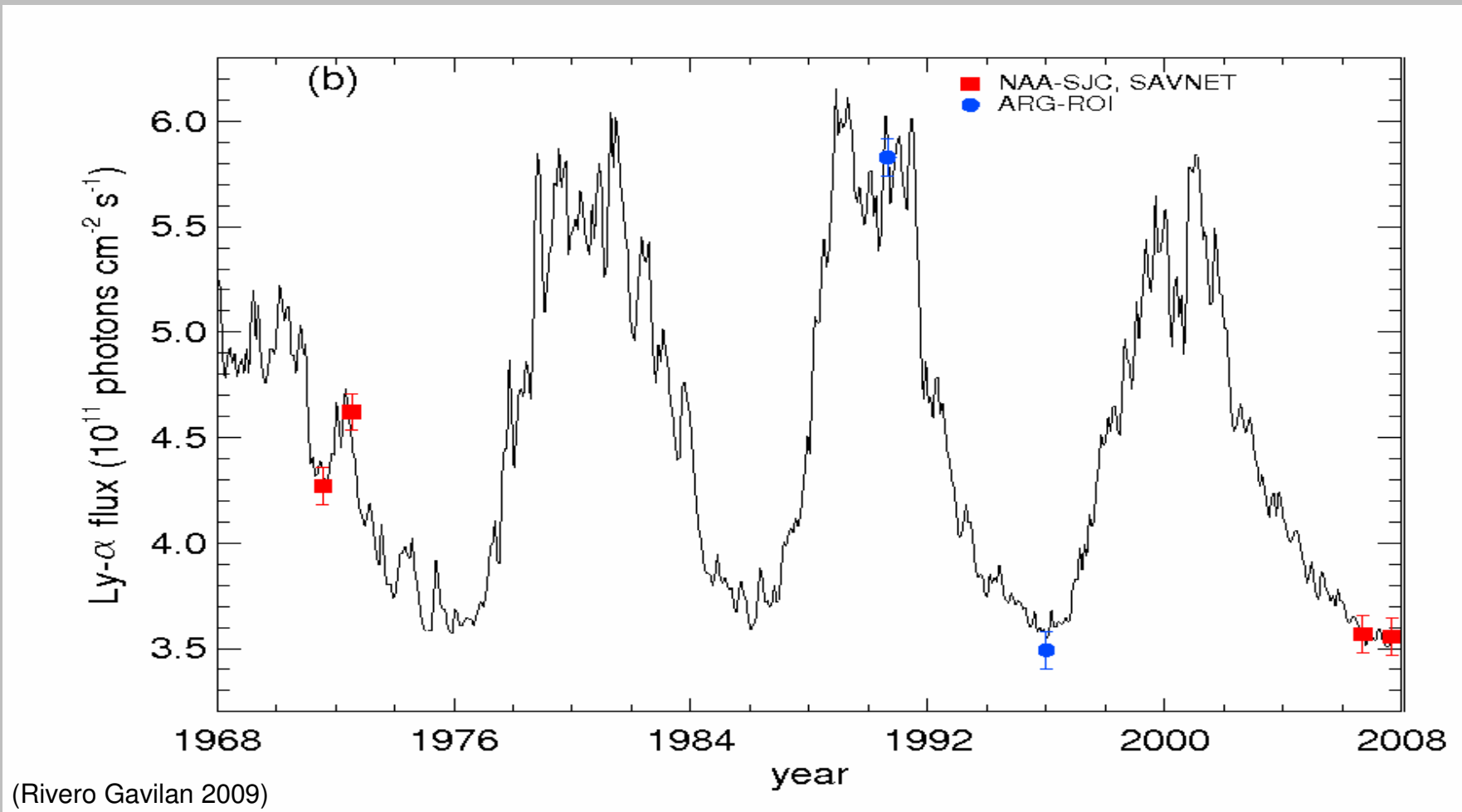
The minimum detectable soft X-ray flux is correlated with the averaged Lyman- α flux : the higher the solar activity the higher P_x



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

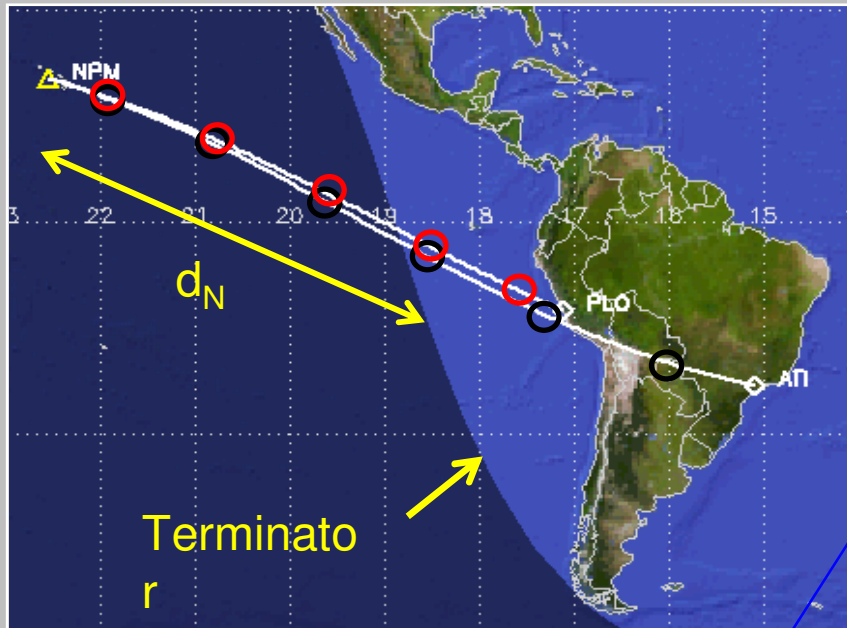


Indirect solar Lyman- α monitoring using the VLF technique

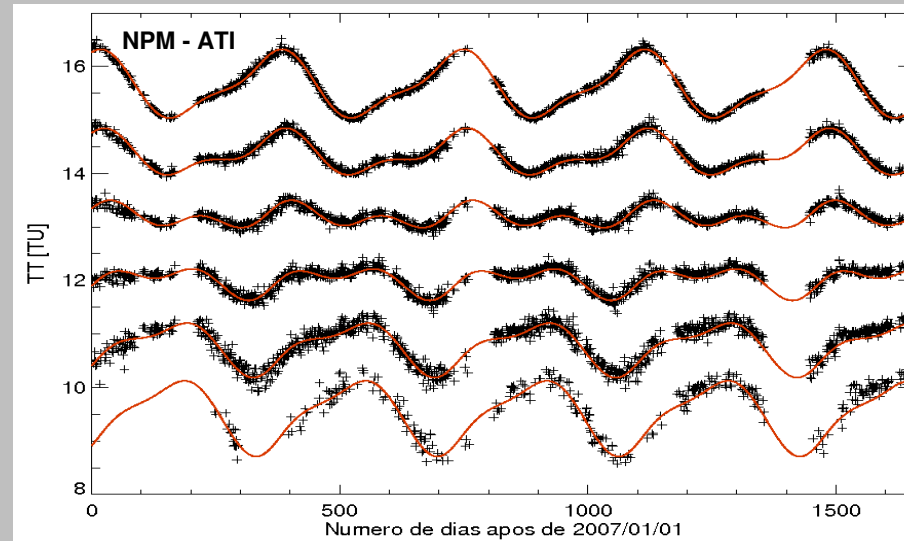
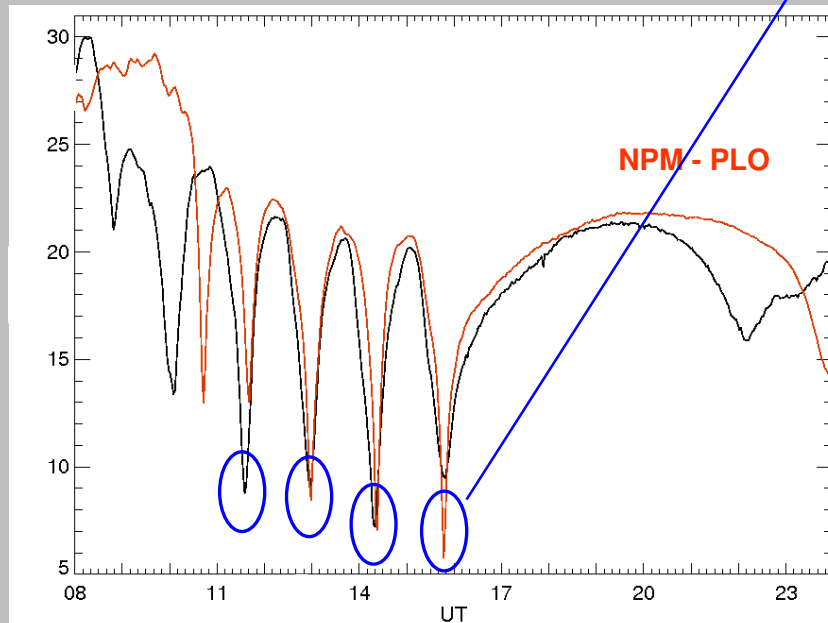
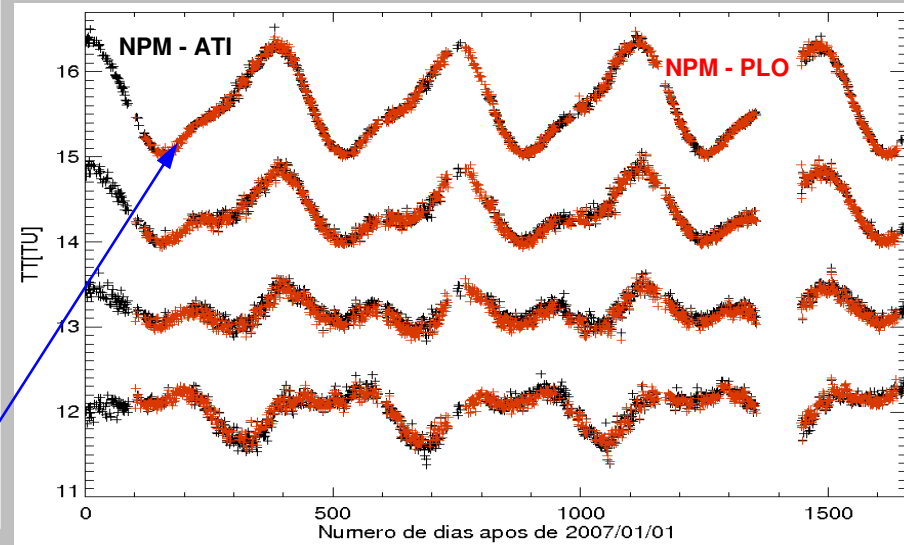
Terminator Time Method

Search for Seismic-electromagnetic effects

(Samanes 2010)

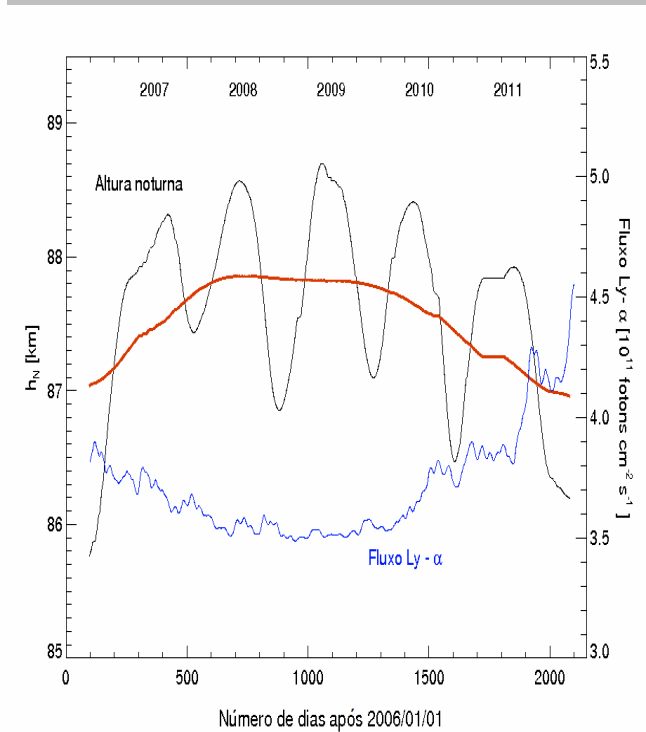
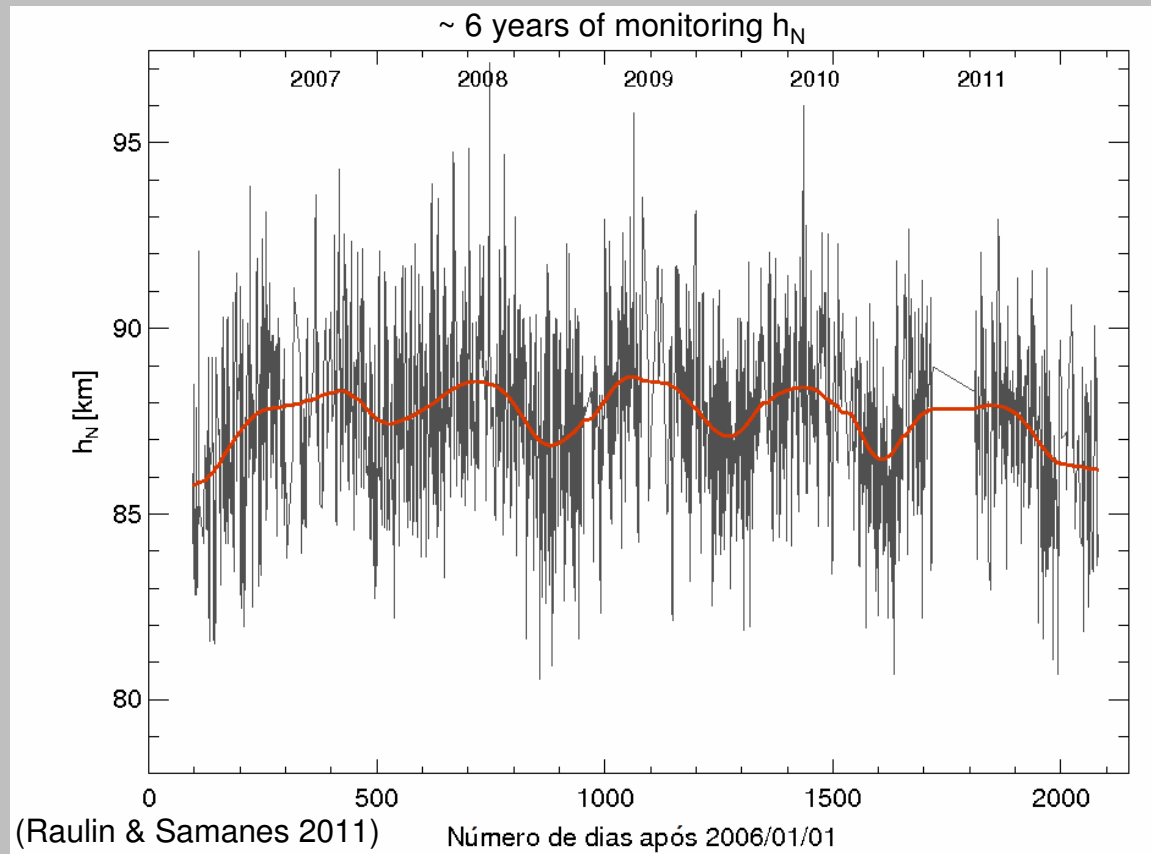


Simultaneous Ttimes for ~ // VLF propagation paths



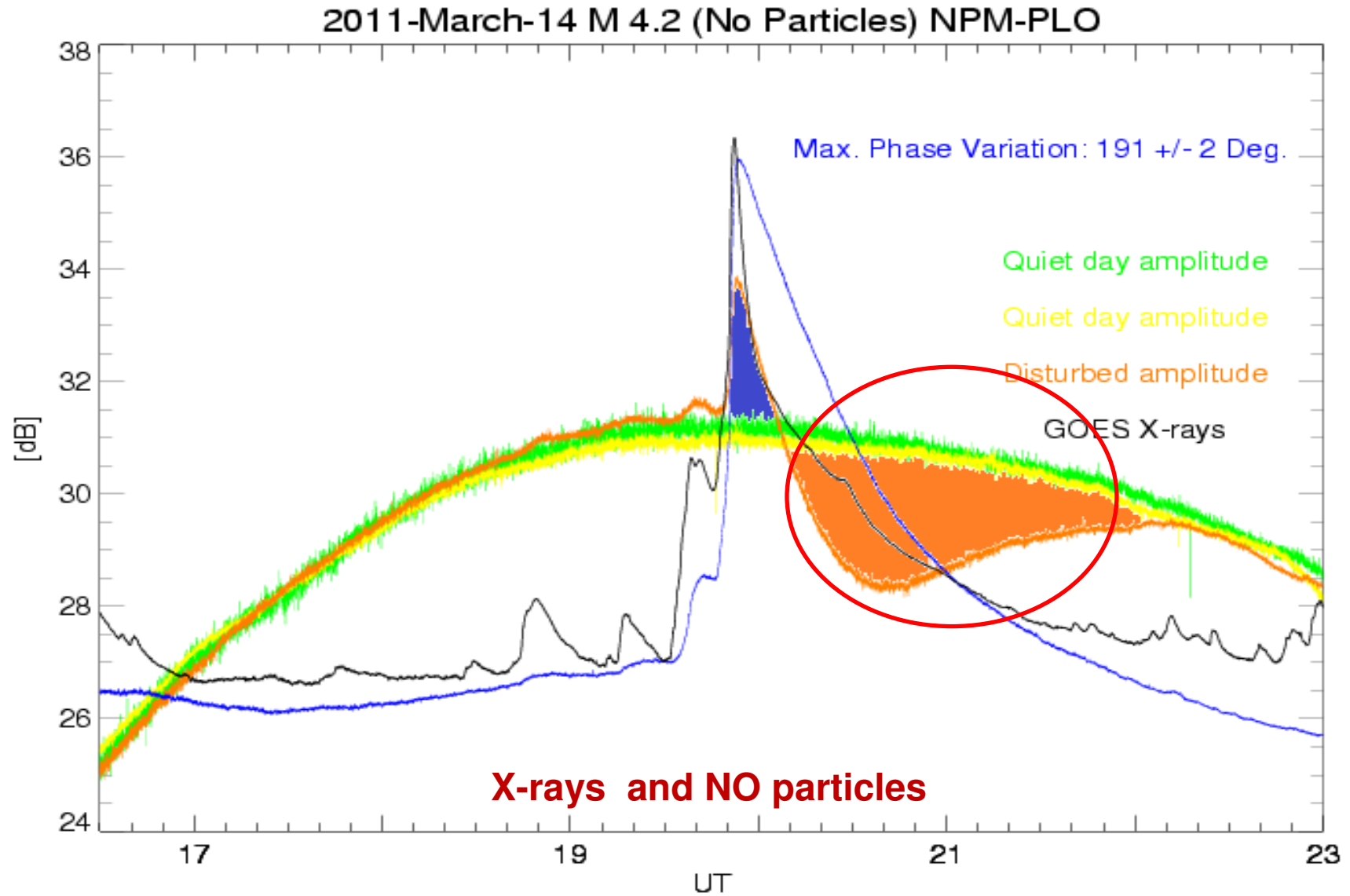
Terminator Time Method

Nighttime ionospheric height h_N

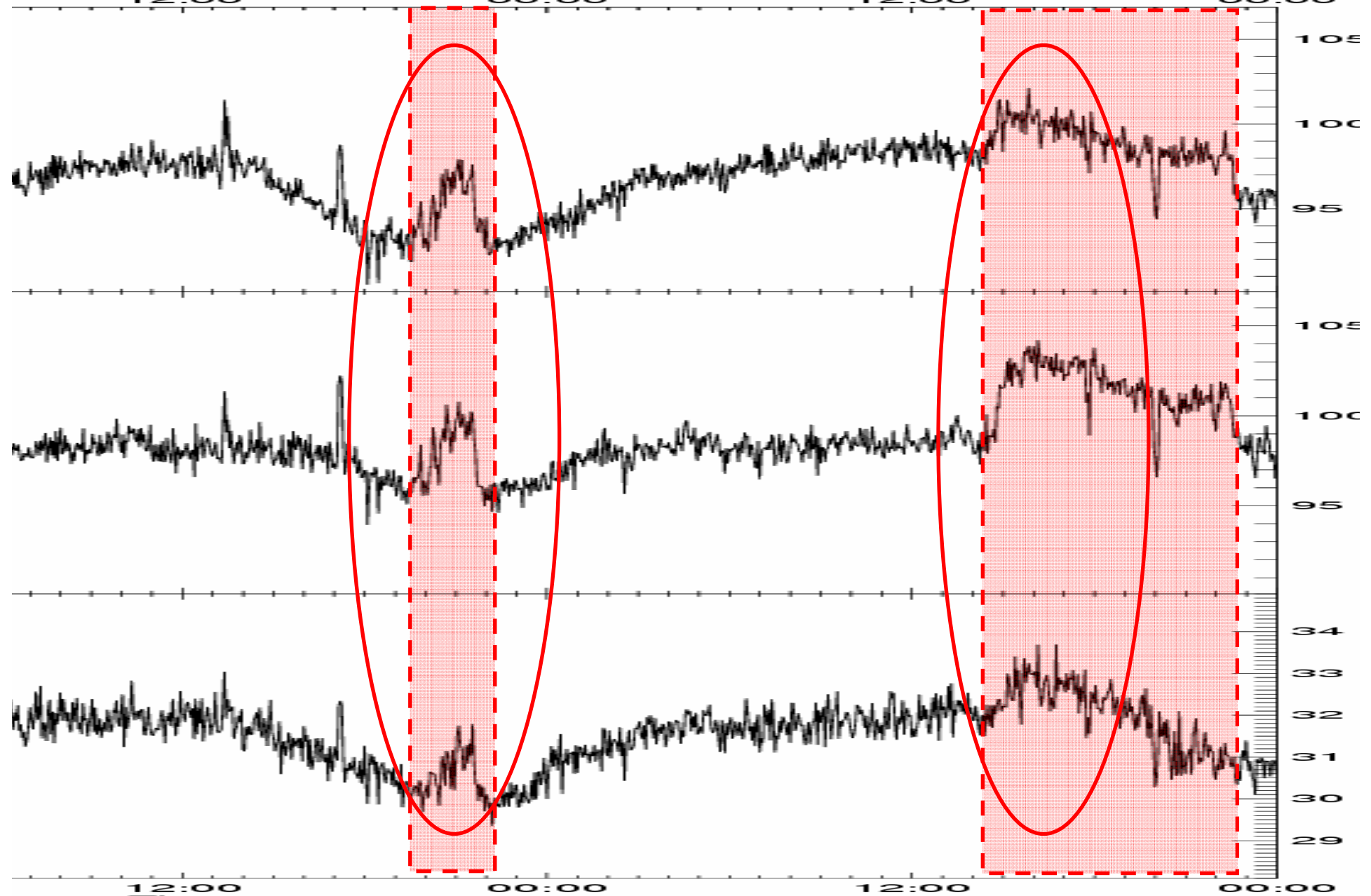


- Clear seasonal variation \rightarrow EM noise from lightning
- Long-term trend probably related to solar activity cycle

SOLAR PARTICLE EVENTS - SPE



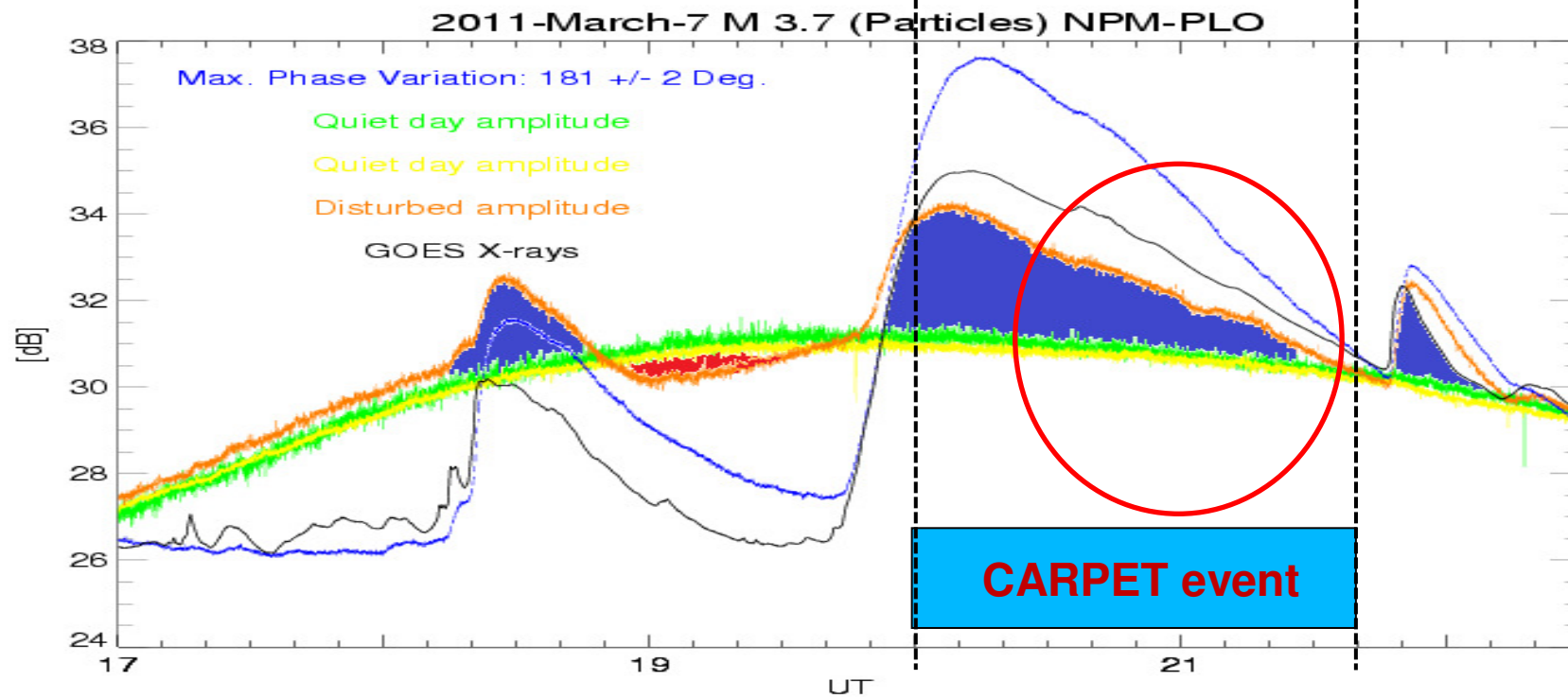
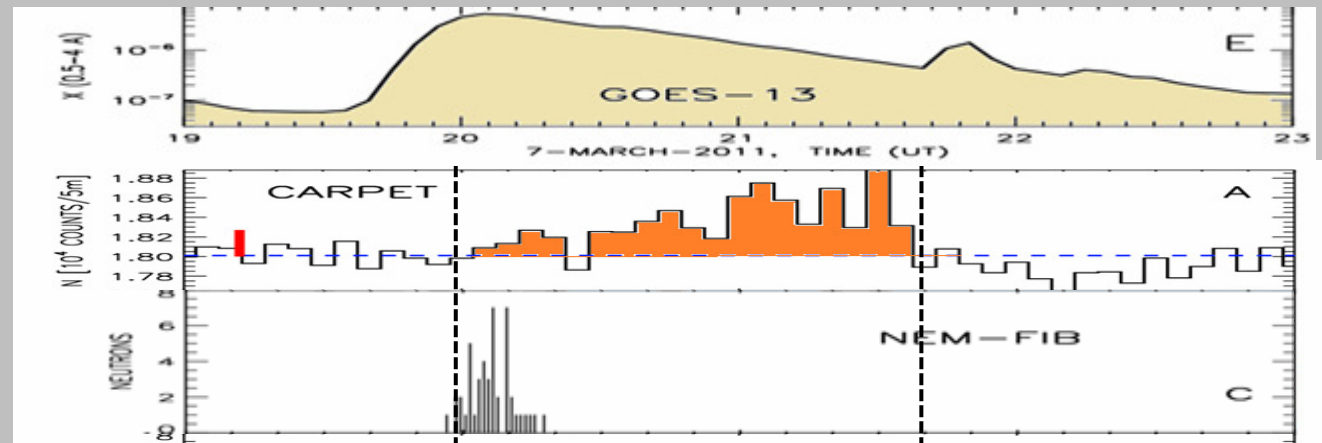
L TIME: 2011/03/09 00:00:00
-04_11-08.save c_plot_ano_moe_1hourly.pro



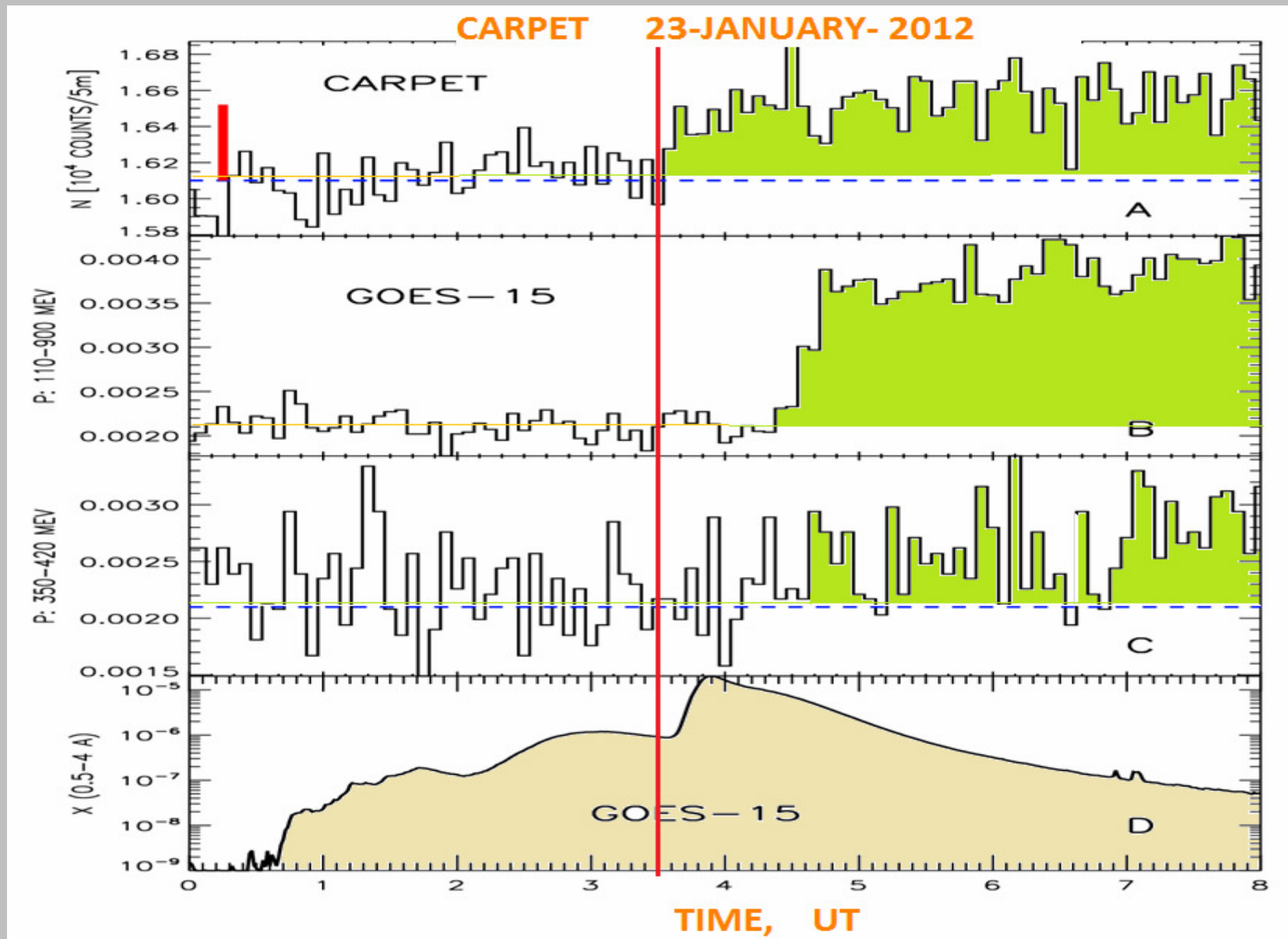
7 MARCH 2011

8 MARCH

**7 - MARCH - 2011
SPE events**



SOLAR PARTICLE EVENTS - SPE

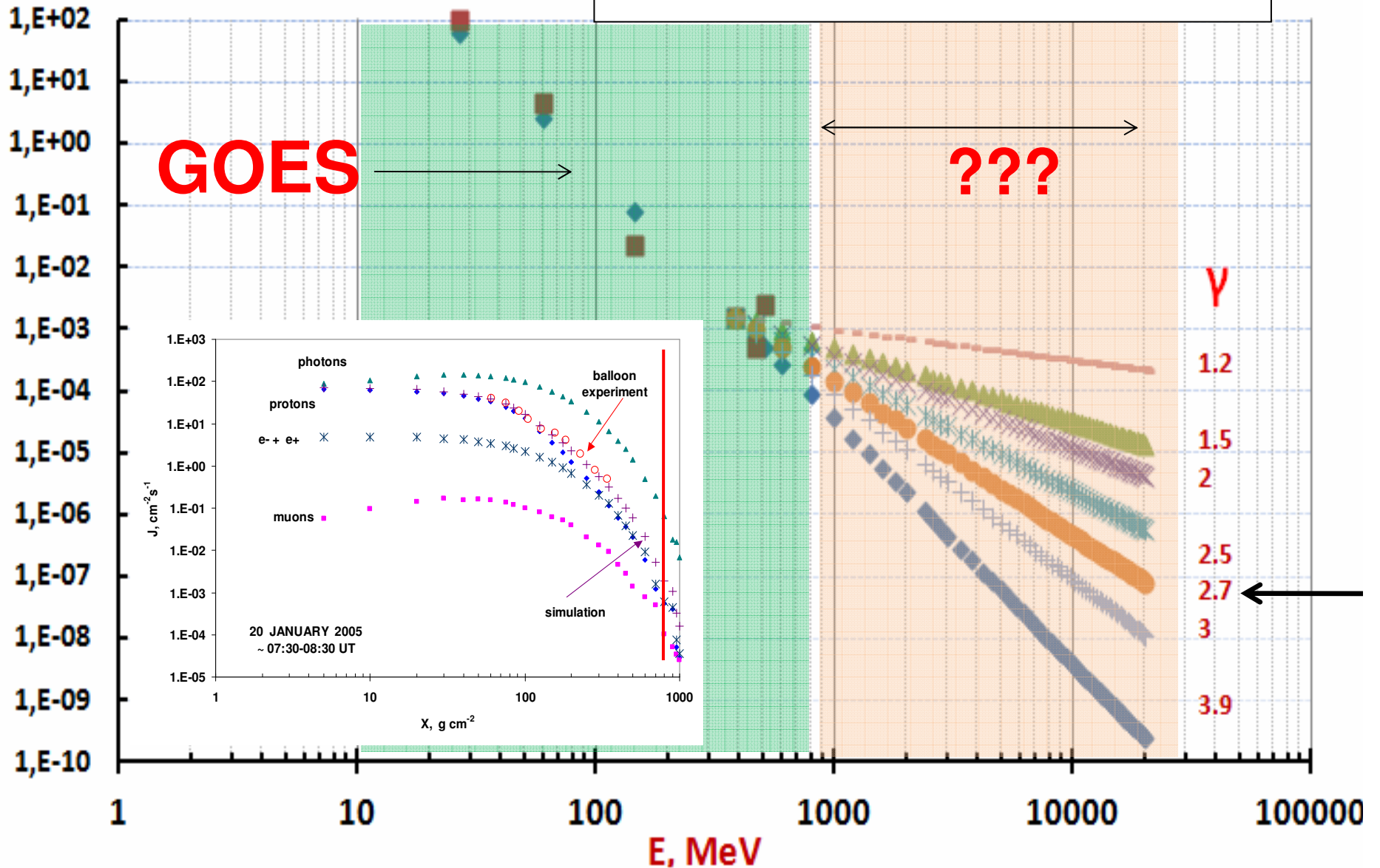


Solar proton spectrum at the top of the Earth's atmosphere:

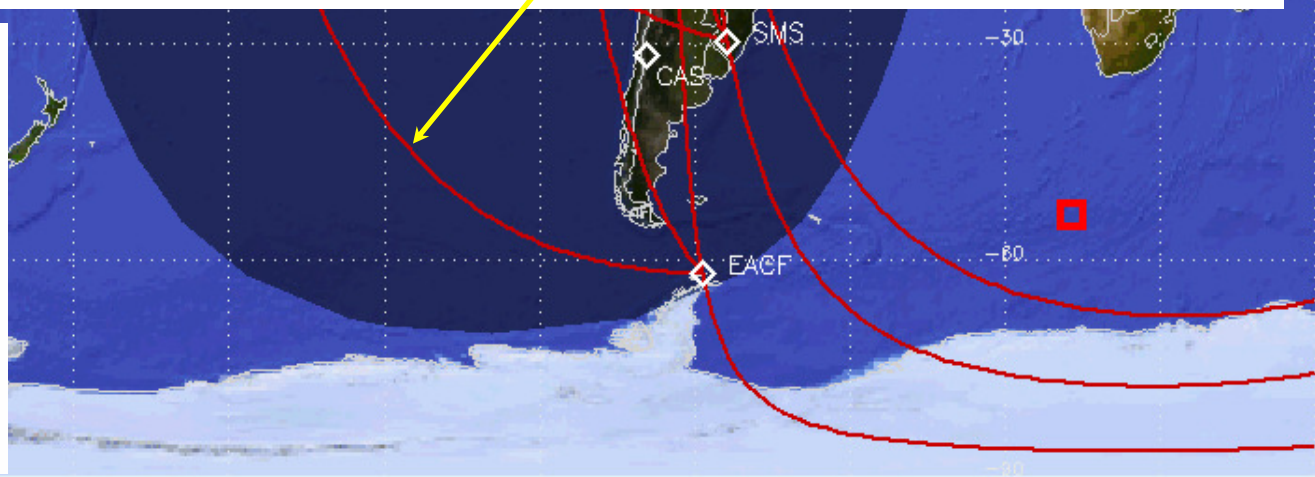
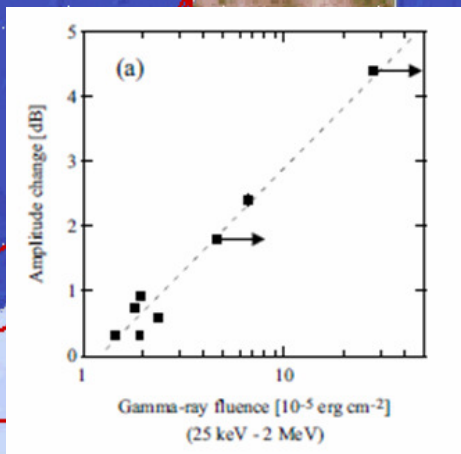
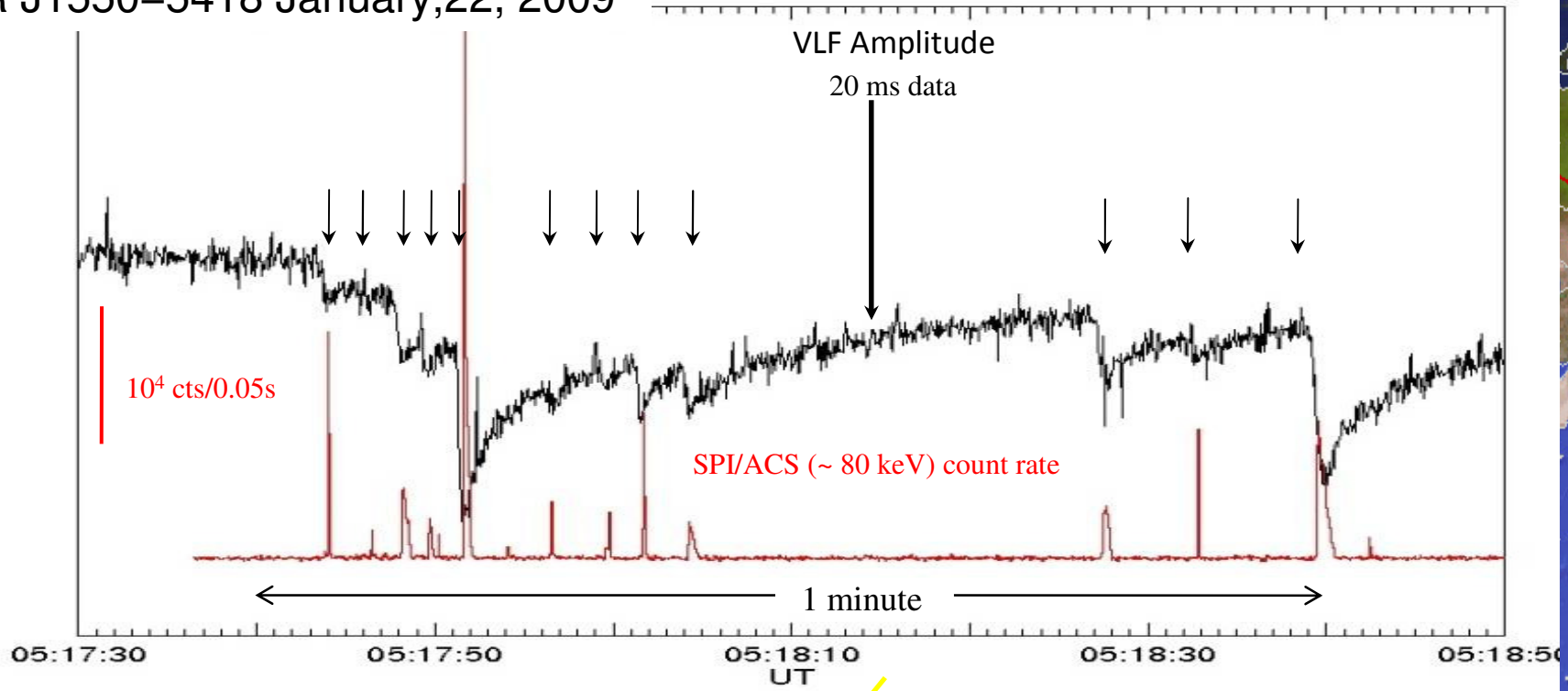
$$J(E) = 3 \cdot 10^7 \cdot E^{-3,9} \text{ p}/(\text{cm}^2 \cdot \text{s} \cdot \text{sr} \cdot \text{MeV})$$

$\text{p}/\text{cm}^2 \cdot \text{s} \cdot \text{sr} \cdot \text{MeV}$

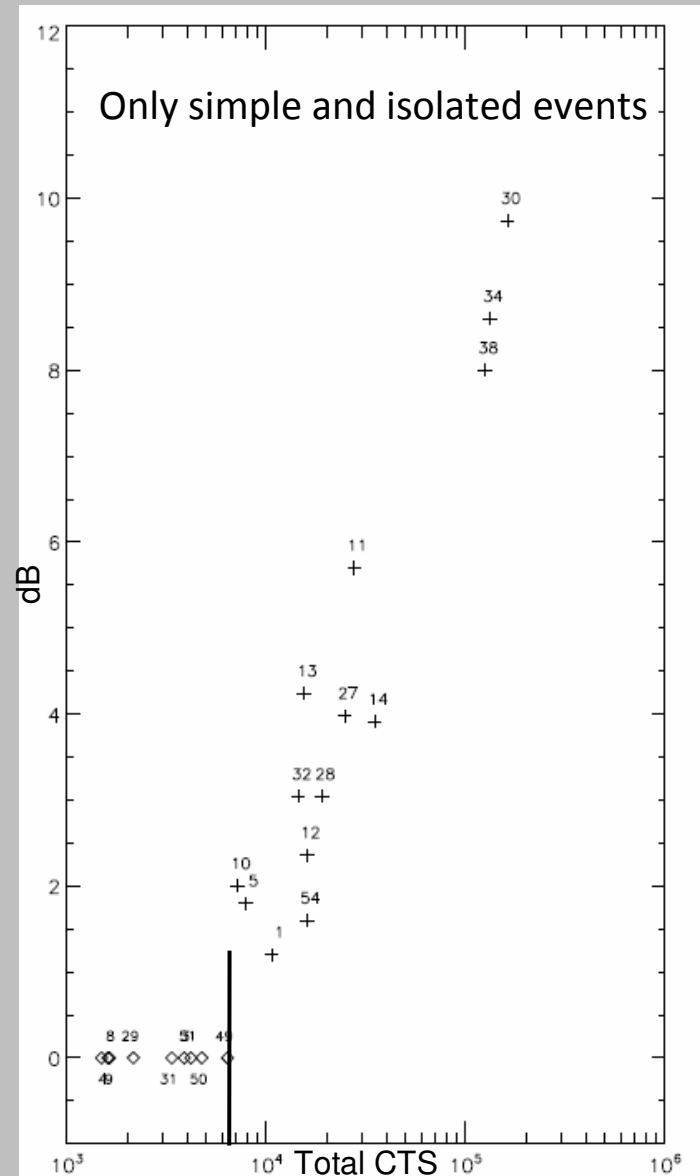
A harder proton spectrum is needed above few GeV



SGR J1550-5418 January, 22, 2009

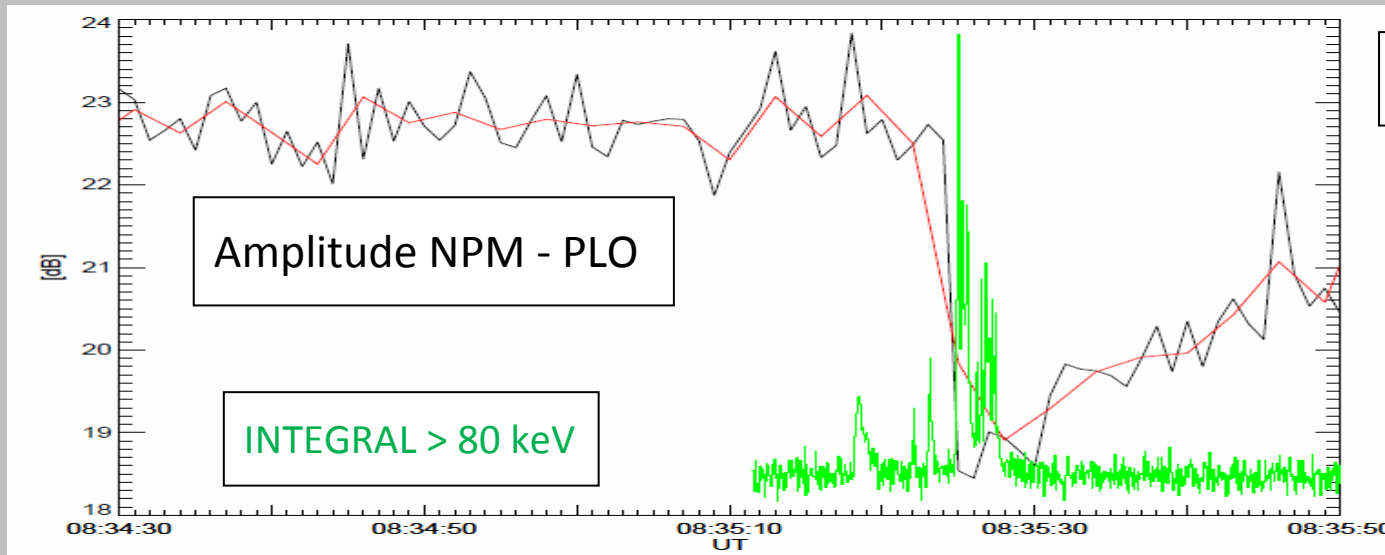
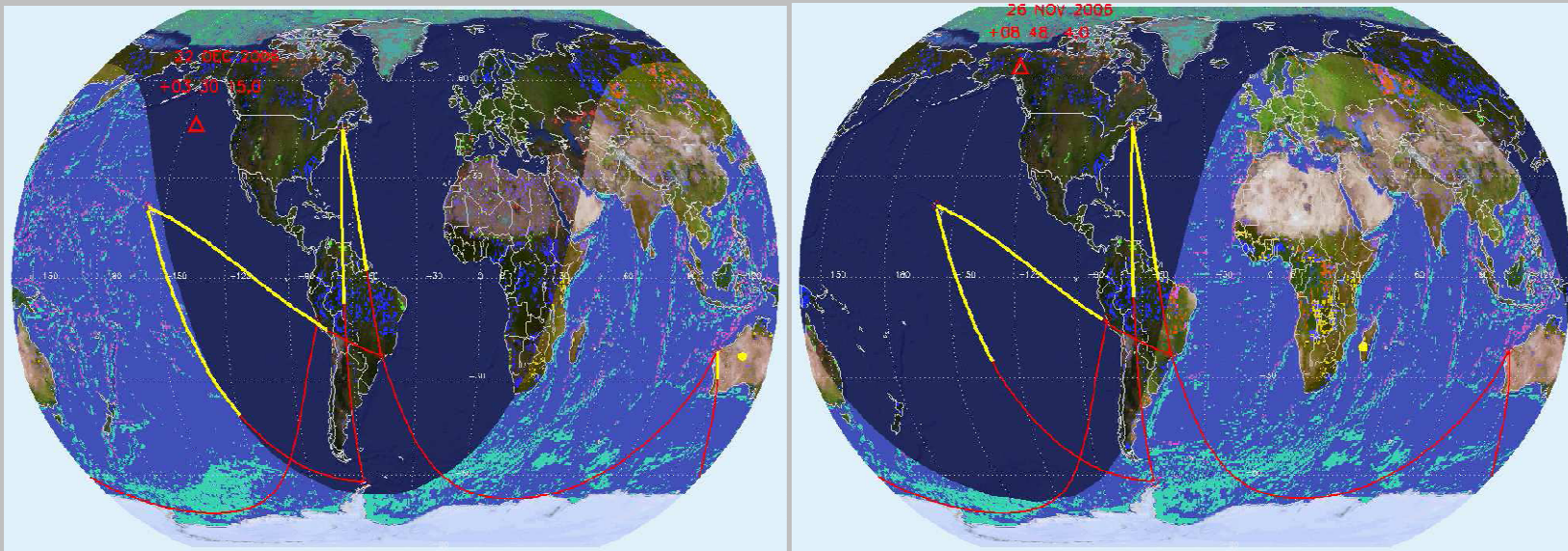


SGR J1550–5418 January,22, 2009



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

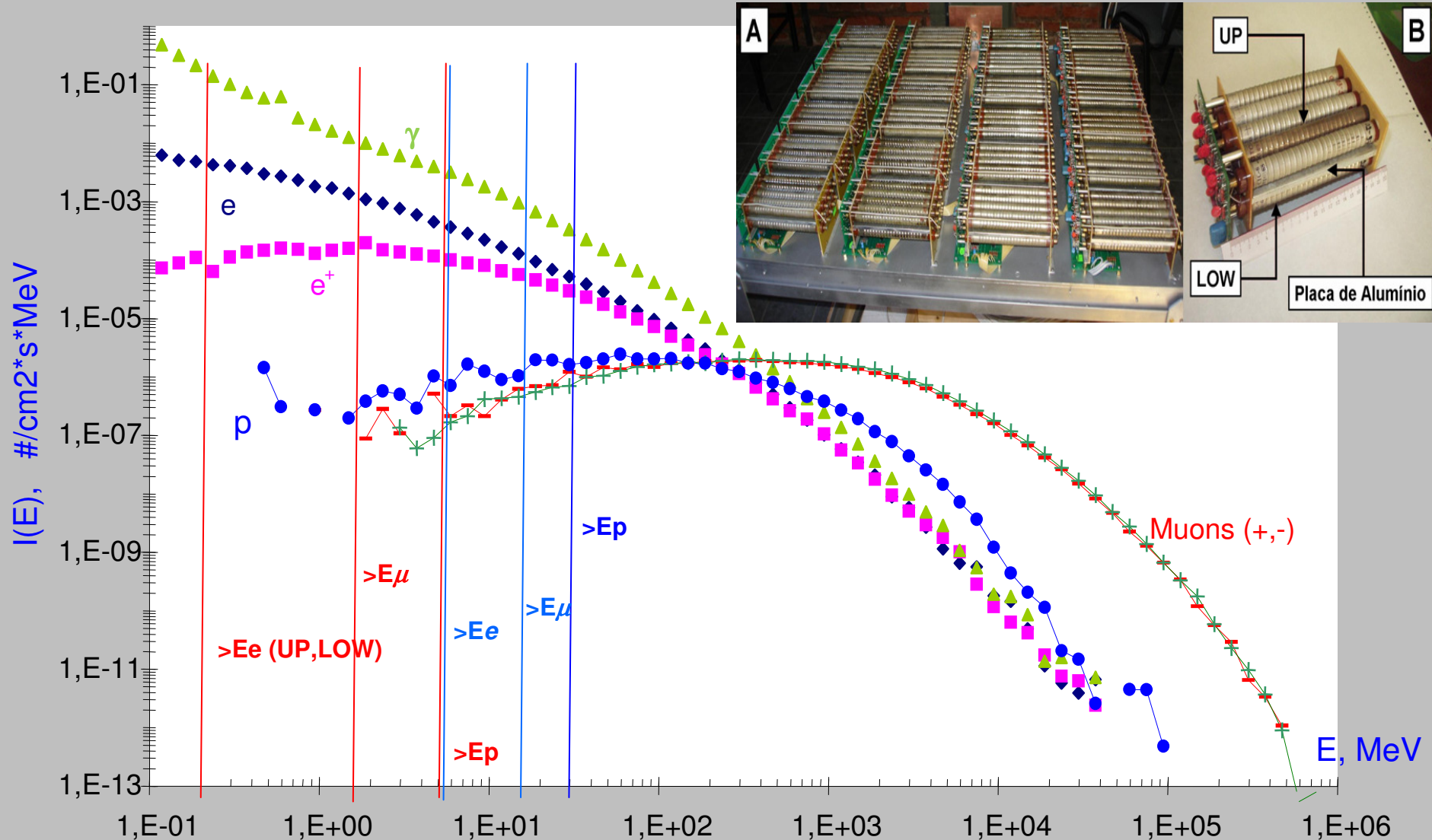
The very simple VLF technique of remote sensing of the low ionosphere has shown to be able to diagnose many aspects of Space Weather phenomena, including disturbances from remote objects of great astrophysical importance.

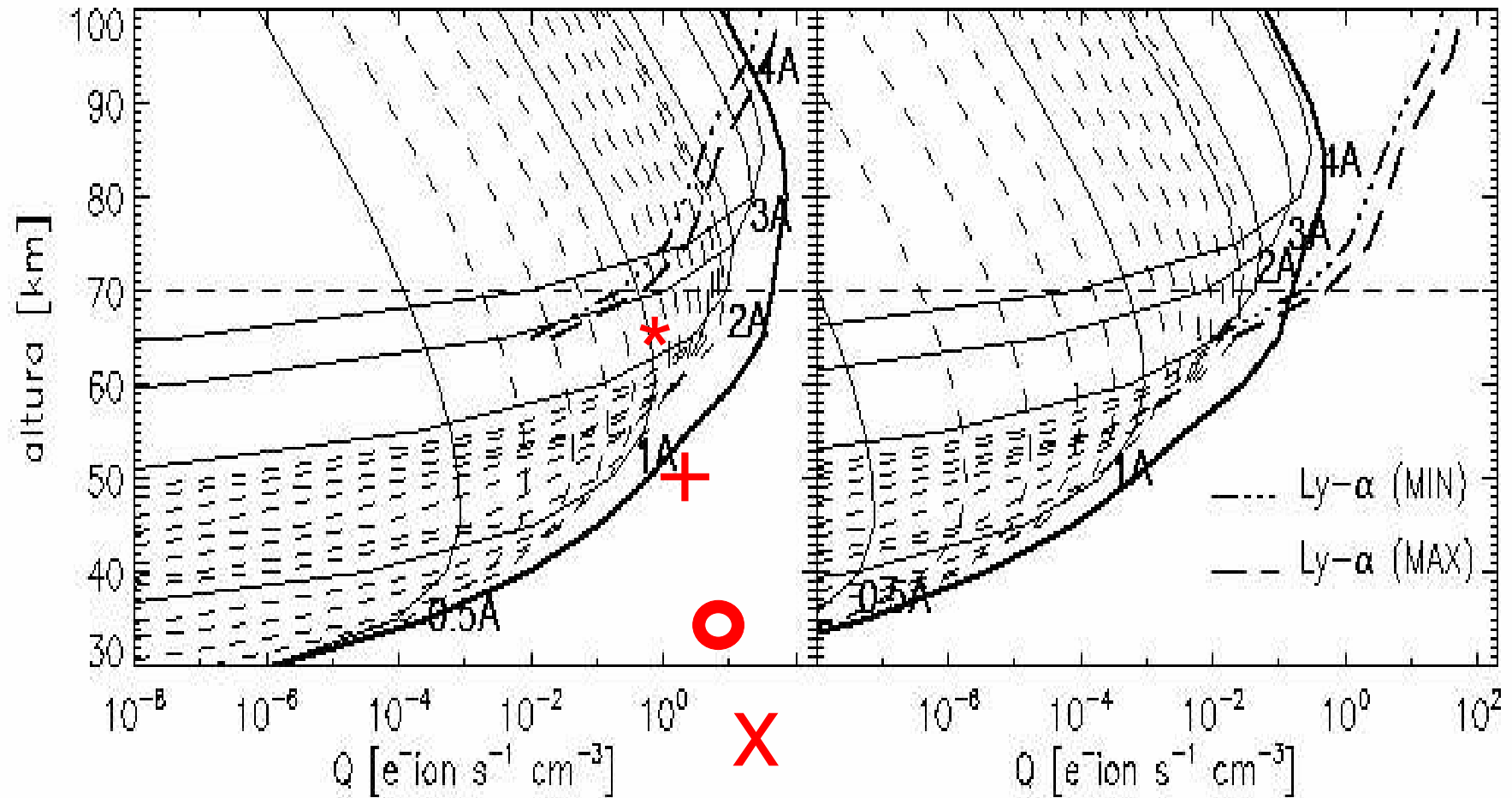
The lower ionosphere plasma is a very sensitive medium to external and internal forcing: radiation, energetic particle fluxes, atmospheric variability.

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 $X=800 \text{ g}\cdot\text{cm}^{-2}$

UP, LOW : $e > 0,2 \text{ MeV}$, $p > 5 \text{ MeV}$, $\gamma > 0,02 \text{ MeV}$, $\mu > 1,5 \text{ MeV}$ TEL: $e > 5 \text{ MeV}$, $p > 30 \text{ MeV}$, $\mu > 15.5 \text{ MeV}$



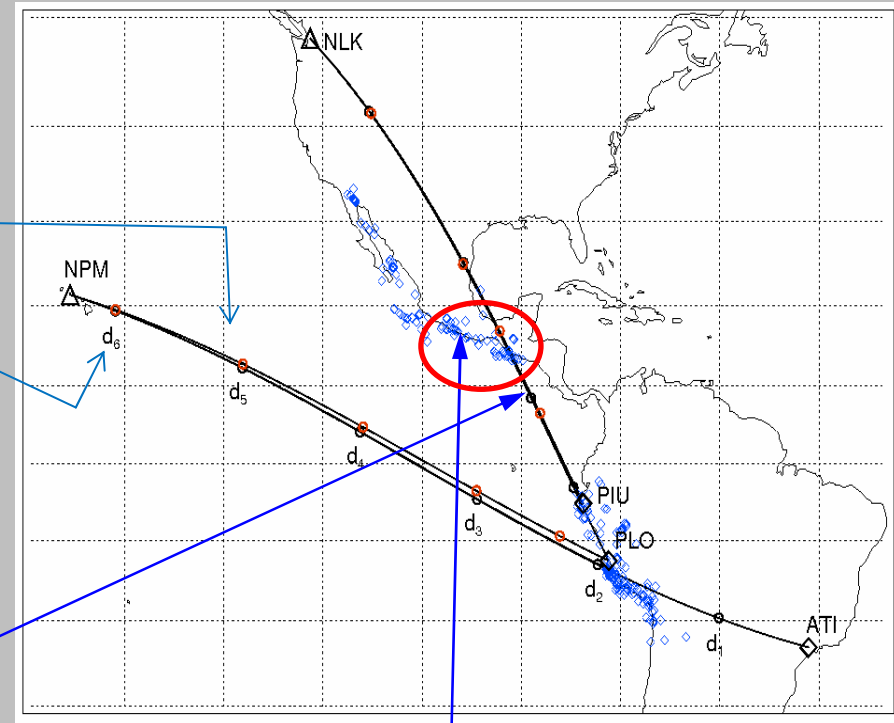
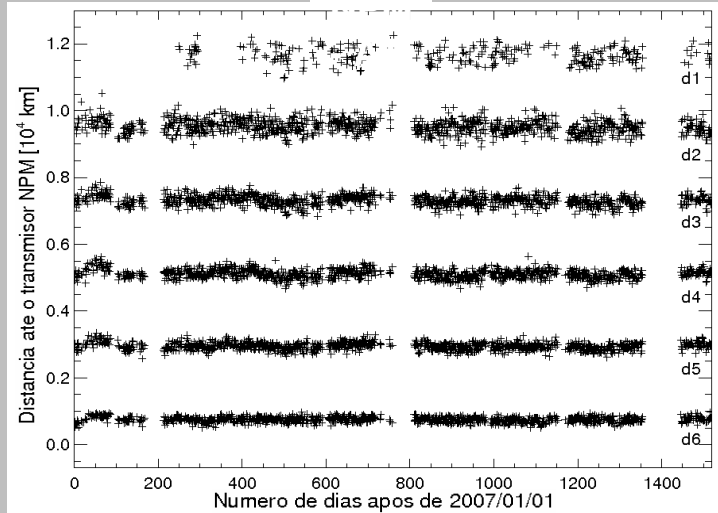


- * 1 proton at 10 MeV (1000 p/cm²/s/sr)
- + 1 proton at 30 MeV (100 p/cm²/s/sr)
- 1 proton at 100 MeV (0.1 p/cm²/s/sr)

- 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

