

# “Solar Flare Emissions from GHz to THz Frequencies”

Grant Number: FA9550-16-1-0072

What can we learn from GHz-to-Mid-Infrared diagnostics of Solar Flares

Jean-Pierre Raulin

Centro de Radioastronomia e Astrofísica Mackenzie - CRAAM  
Engineering School  
Universidade Presbiteriana Mackenzie  
São Paulo, Brazil



Proc. 2013/24155-3



FA9550-16-1-0072

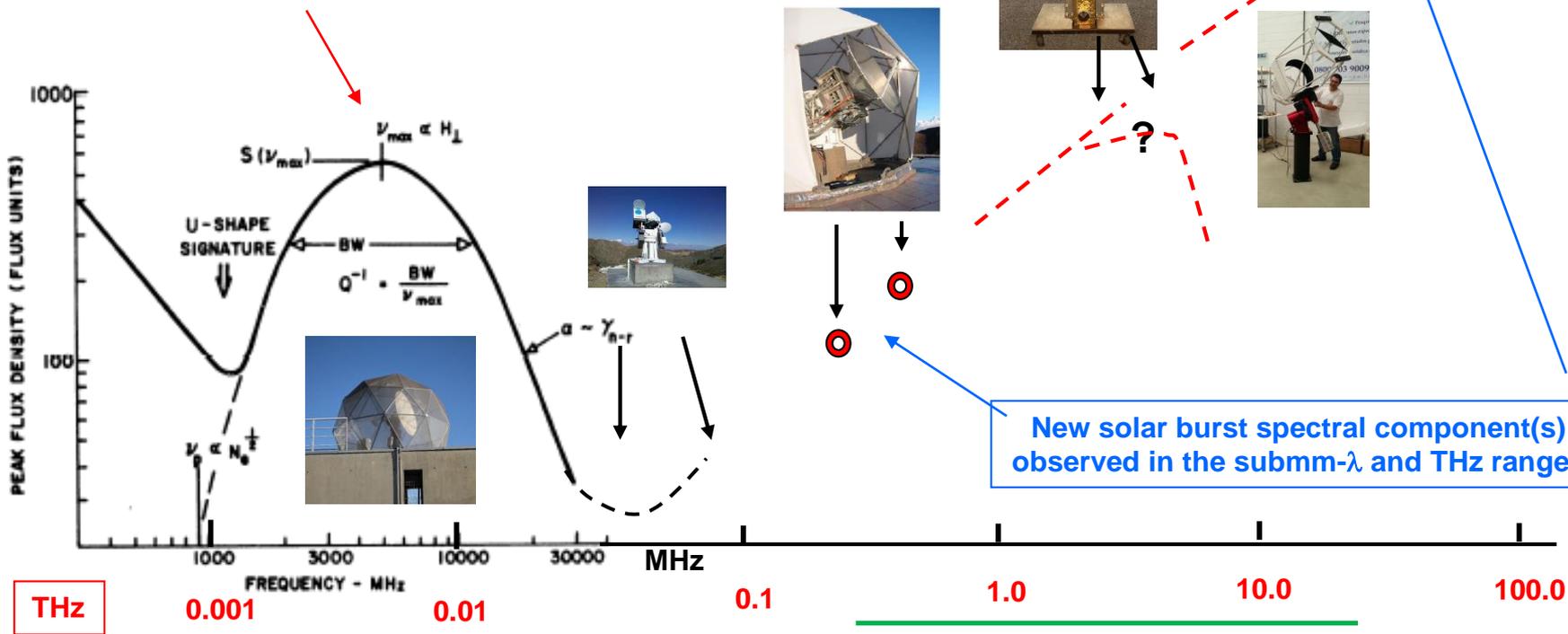


Proc. 312066/2016-

# INDICATION OF ANOTHER SOLAR BURST CONTINUUM SPECTRUM IN THz



**U-shaped spectrum (Castelli 1972)**  
Assumed as typical and common to all bursts



Kaufmann et al. (2004; 2009) Luethi et al. 2004; Trotter et al. 2008; 2011); Silva et al. 2007; Raulin et al. (2003; 2004; 2014)



**SUN-TERAHERTZ onboard ISS**  
0.2 – 15 THz

**OBSERVATIONS IN THE THz RANGE ARE NEEDED TO UNDERSTAND THE EMISSION MECHANISMS INVOLVED**

SOARD Program Review, Santiago, Chile, March 20, 2019



# FA9550-16-1-0072 Highlights

- Installation and operation of 7 GHz polarimeter at UPM**

Automatic routine observations of free-free and non-thermal emission from solar active regions

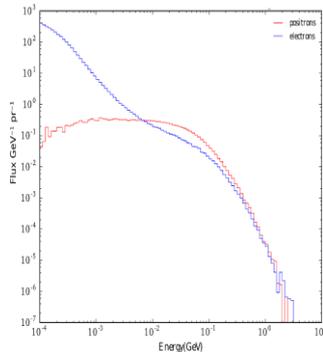


- HATS: High Altitude Terahertz Solar telescope – 16 THz**

- Sub-systems integration: mount + optics + Golay
- Installation at OAFA (2550 masl) mid-2019
- Complete the THz spectrum of quiet and active Sun
- During solar flares → 10 % excess above Quiet Sun
- OTTB



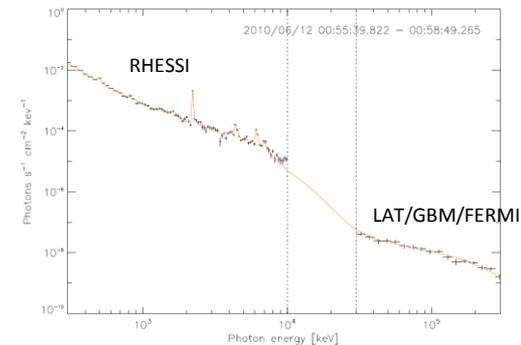
- Positron and secondary electrons production during flares**



- FLUKA simulation from up to 20 GeV primary proton spectra
- Transport of 2ndary particles included
- Knock-on electrons ( $\delta$ -rays)
- “electron number problem” → few  $10^5$  SFU at 90 GHz
- Not enough positrons for 2003/11/04
- GEANT4 → B-field

- Self consistente modelling of GR spectra from solar flares with FLUKA**

Provide templates with FLUKA for the full GR spectrum componentes: nuclear de-excitation lines, 511 keV annihilation line, 2.2 MeV captures line, and pion decay continuum



## Published papers

[9 papers](#) were published in Solar Physics, Journal of Atmospheric and Solar-Terrestrial Physics, Space Weather, Astronomy & Astrophysics, The Astrophysical Journal Letter, Journal of Geophysical Research: Space Physics.

## Submitted papers

[7 papers](#) are submitted in Solar Physics, Astronomy & Astrophysics

## Papers in Conference Proceedings

[5 papers](#) in proceedings

## Invited talks

[15 invited talks](#) in national and international events including COSPAR, XI COLAGE, SCOSTEP, EXPUNIV2018, MEUDON/VLF, LPI/MOSCOW, VII SBGEA, SAB, SPANet, EWASS, URSI

## Human Ressources

[2 PD Fellow, 6 PhD, 7 Master Degrees, 5 IC involved](#)

## Institutional Recognition

- Mackenzie University Support: hiring one project manager, one chief-engineer, one researcher
- Award for the 2018 highest scientific production at Mackenzie University

## Next ?

# On the Origin of Solar Flares at very high frequency, and Solar Flare Impacts on the Earth's Atmosphere

### Solar flares at very high frequency (from microwaves to IR)

- Role of synchrotron emission from positron in Solar Flares
- Role of secondary electrons: “electron number problem”
- Mid-IR 30 THz (10 microns) versus White-Light flares
- Atmospheric models for quiet and active Sun

New experiments: SUN-TERAHERTZ, HATS

Existing: SST, 90 GHz polarimeters POEMAS, 30 THz telescopes

### Impacts in the atmosphere of the Earth (Space Weather)

- Solar (and non-solar) ionizing effects in the ionosphere
- Solar and Geophysical impacts on the Global Atmospheric Electric Circuit
- HF absorption during solar flares

Existing: SAVNET, AFINSA, SARINET, network of Ionosondes

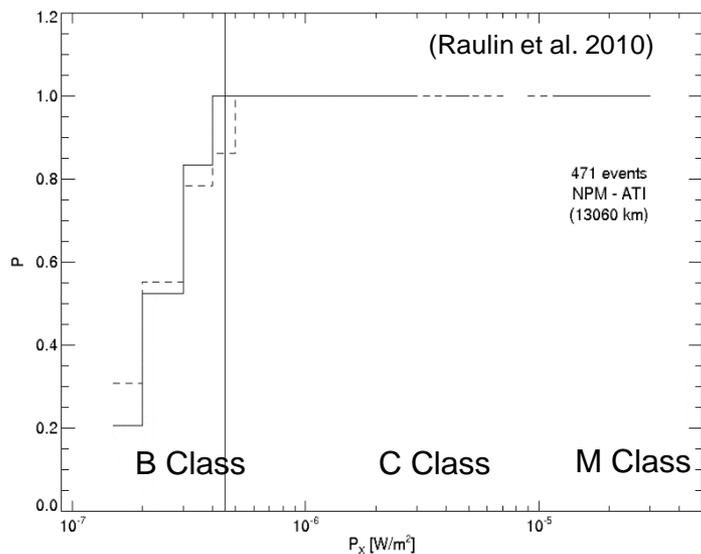
# TRANSIENT SOLAR FORCING IN THE EARTH'S IONOSPHERE

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

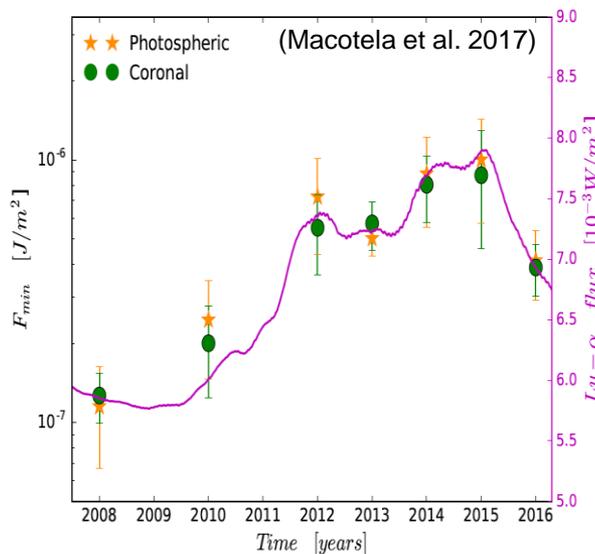
→ VLF propagation anomalies → VLF phase and amplitude changes

**Solar:** quiescent, Ly- $\alpha$ , X-rays (flares), particles (SEPs); **Non-Solar:** X-rays, GRB, flares from SGR

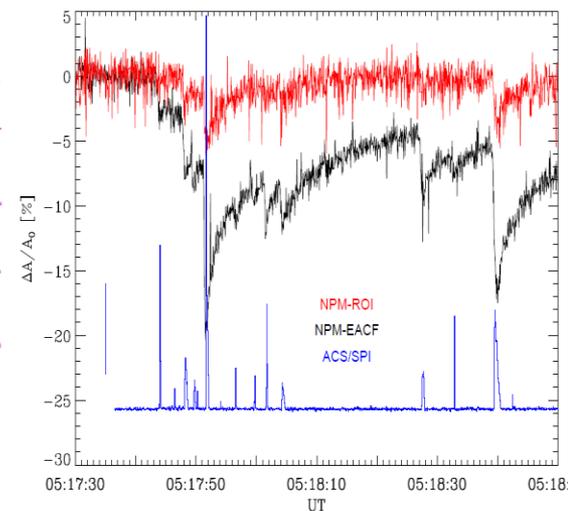
≥ B4 Class events are detected with 100 % probability



$F_{min}$  is well correlated with reproduces the solar Lyman- $\alpha$  photon flux



Non-solar remote cosmic burst

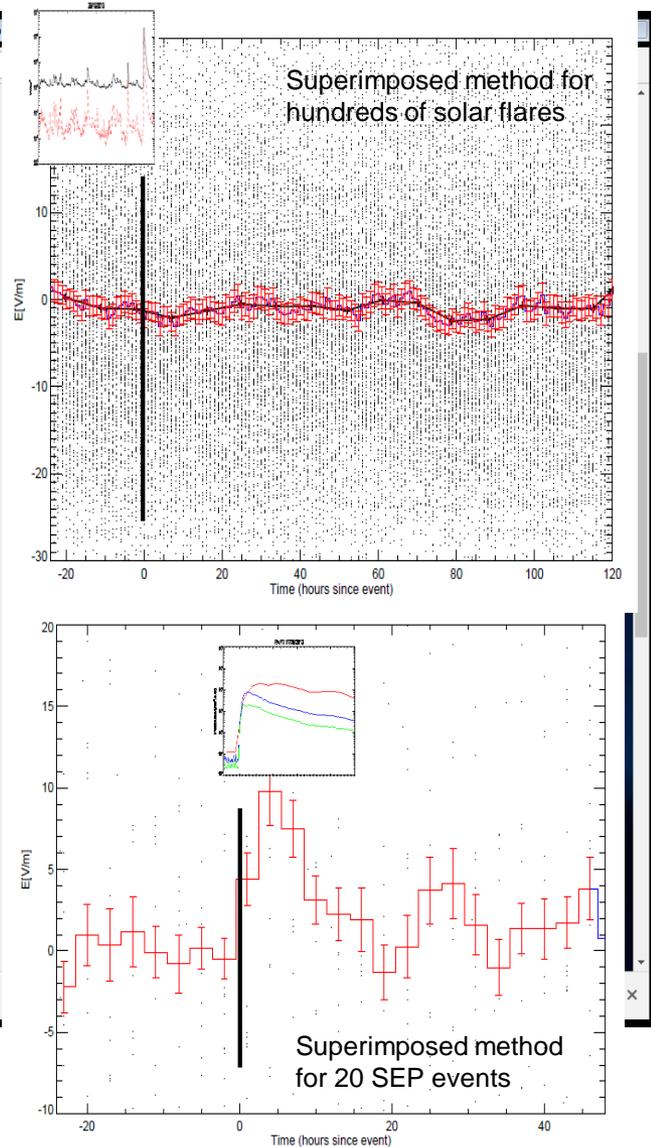
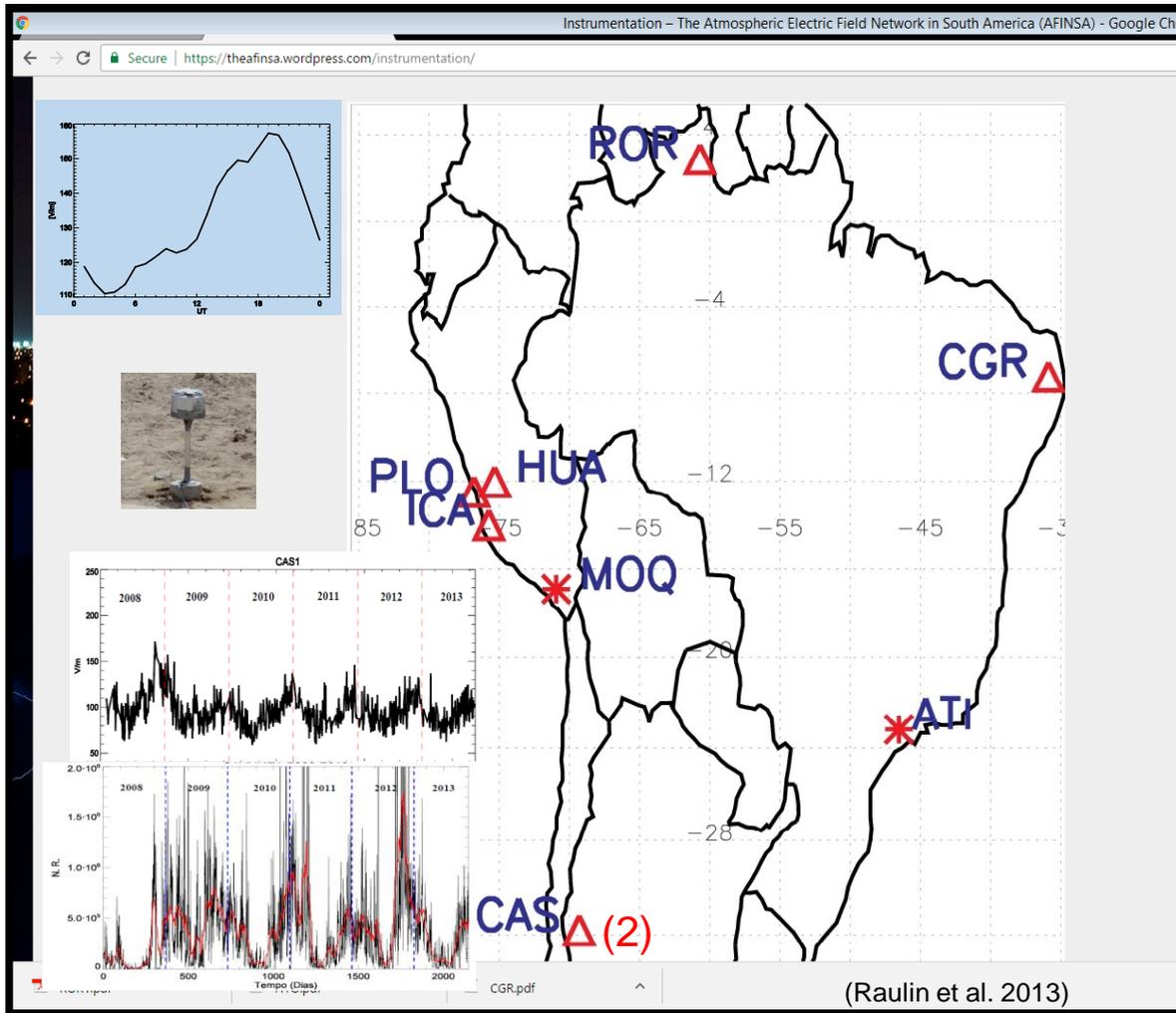


Ionospheric indice for the solar Ly- $\alpha$  radiation

During cosmic bursts VLF,  $\Delta\Phi$ ,  $\Delta A$  changes are  $\propto$  with the X-ray fluences  $F_{25}$

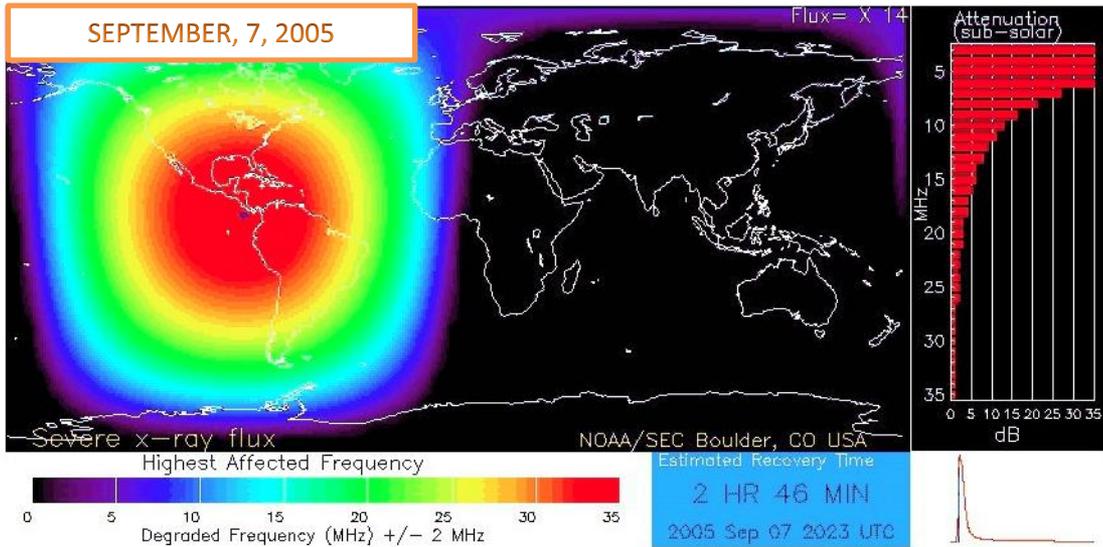
# The AFINSA network <https://theafinsa.wordpress.com/>

## Atmospheric Electric Field - GAEC



# Ionospheric HF absorption

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

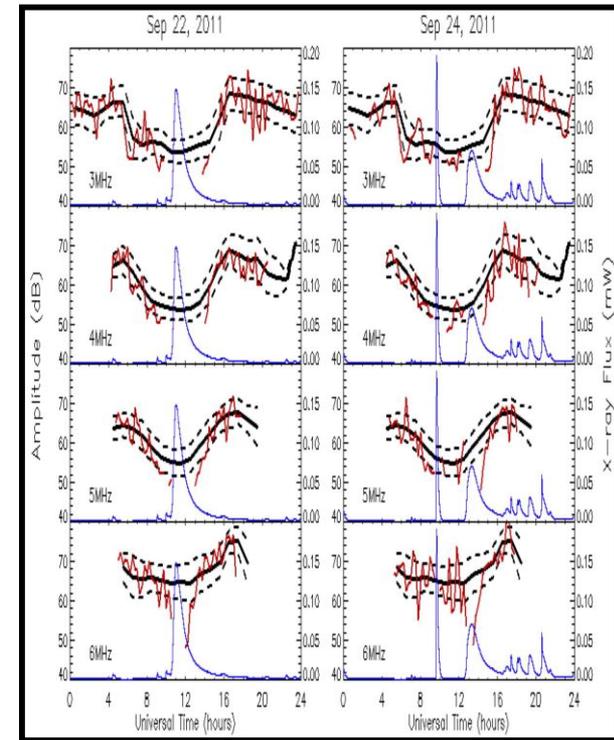


- Photons versus particles
- Riometers of high latitude
- Photon energies
- ionosondes

$$\text{HAF [MHz]} = 10. \log[\text{flux}_{1-8} (\text{W/m}^2)] + 65$$

Absorption at any given frequency  $f$  :

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



Tshisaphungo and Danskin, 2016

# Conclusions

Despite the loss of former FA9550-16-1-0072 PI, Prof. P. Kaufmann, research activities and development went smoothly.

FA9550-16-1-0072 brought important results on the atmospheric transmission at submillimeter wavelengths, solar flare emissions from microwaves to THz frequencies and mid-IR.

Developments of new instrumental facilities at 30 THz, their installation, operation and exploration were successful.

Operation at 16 THz (HATS telescope) almost complete.

Research activities related to FA9550-16-1-0072 resulted in:

- 21 (9 + 7 + 5) papers
- 6 PhD, 7 Master formed; 2 PD Fellow involved
- 15 invited talks
- 1 Chief-Engineer, 1 Project Manager, 1 Researcher hired

In a next proposal we propose to study:

- $\mu$ w-IR Solar flares  $\rightarrow$  2nd e-, positrons, mid-IR versus WL, atm, models
- Impacts in the Earth's atmosphere (Space Weather)  $\rightarrow$  ionosphere, GAEC, HF absorption.