Observation of a Terrestrial Electron Beam during the tropical cyclone Joaninha in March 2019

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SAINT Science and Innovation With Thunderstorms — H2020 Marie Skłodowska-Curie Initial Training Network

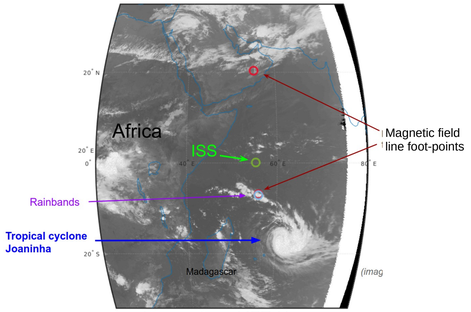
Abstract

Terrestrial Gamma-ray Flashes (TGFs) are short (~10 us to ~2 ms) flashes of high energy (< 40 MeV) photons, produced by thunderstorms When interacting with the atmosphere, the TGF's photons produce relativistic electrons and positrons at higher altitudes, and a fraction is able to escape the atmosphere **[1,2,3]**. The electrons/positrons are then bounded to Earth's magnetic field lines and can travel large distances inside the ionosphere and the magnetosphere. This phenomenon is called a Terrestrial Electron Beam (TEB).

The Atmosphere-Space Interactions Monitor (ASIM), dedicated to the study of TGF and associated events, started to operate in June 2018. ASIM contains an optical instrument (MMIA) made of micro-cameras and photometers, as well the Modular X and Gamma-ray Sensor (MXGS) for high energy radiation. MXGS is composed of the low energy detector (LED, 50 keV to 400 keV) and the High Energy detector (HED, 300 keV to 40 MeV).

This presentation is focused on a new event which was detected on March 24, 2019. The TEB originated from rainbands produced by the tropical cyclone Joaninha, in the Indian Ocean, close to Madagascar. This observation shows, for the first time to our knowledge: (1) the low energy part (>50 keV) of the TEB spectrum, using the LED, (2) an estimate of the incoming direction of the electron Beam from recorded data.

Maps of the event

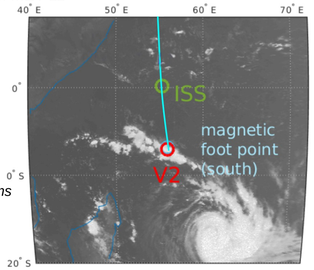


Images from MET-11

Event time : 2019-Mar-24 00:31:53.135444 (UTC)

V2 = VAISALA (GLD360) sferic match (i.e. associated lightning discharge)

- *Delta time = -0.9639 ms*
- distance to ISS: *≈800 km*
- *Distance mag foot-point to V2 : 4.82 km*
- *Uncertainties:*
  - *MXGS absolute timing uncertainty ~ 20 ms*
  - *V2 Location : ~ 15 km*



Monte-Carlo simulations

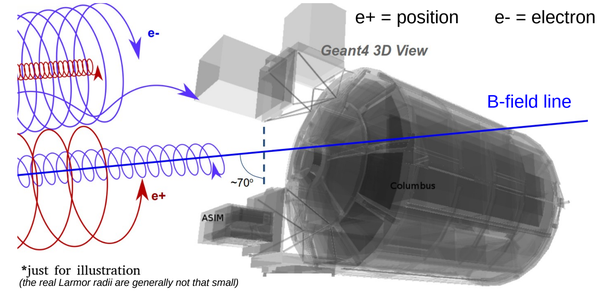
***Forward modeling strategy,* 2 stages :**

I: TGF generation, e+/e- production, and propagation in the atmosphere

- Geant4-based
- Uses IGRF-12 or WMM for the magnetic model (very similar).
- Uses the NRLMSISE-00 model for the atmosphere composition
- Only *fully-developped-RREA* TGF model tested (i.e. ~1/E*exp(-E / 7.3MeV)), so far
- Code available here : https://doi.org/10.5281/zenodo.2597039

II: Response of the instrument + environement

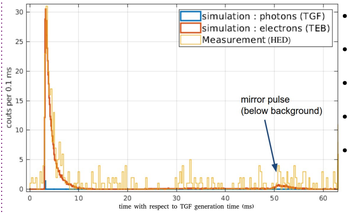
- Geant4-based
- Developped by B.E. Carlson
- Includes ASIM + ISS's Colombus module



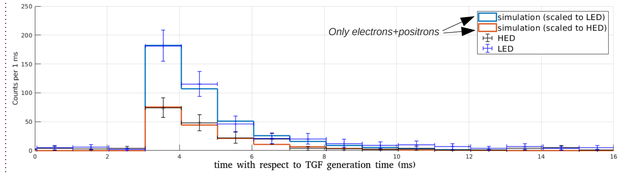
*just for illustration
(the real Larmor radii are generally not that small)

Lightcurves

Lightcurve =
recorded counts (LED or HED) due to electrons and positrons, as function of time.

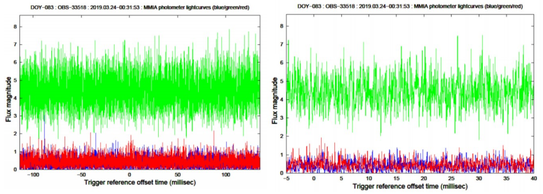


- HED : 400 keV to ~30 MeV, recroded count number: ***375***
- LED : 50 keV to 370 keV, recroded count number: ***175***
- LED/HED ratio from *simulation (2.08)* and *measurement (2.15)* are consistent
- Simulated lightcurve weakly changes with energy
- Simulation predicts a mirror pulse at ~50 ms, but below background level



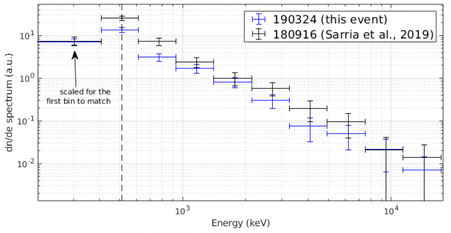
MMIA photometers

180-240 nm (ultraviolet)
337 nm (near ultraviolet)
777 nm (red)



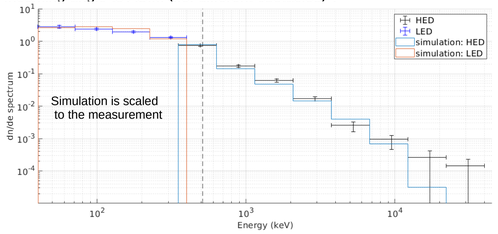
- Field of view ~400X400 km² below ISS
- Nothing, as expected (lightning ~800 km away)

Preliminary spectral analysis



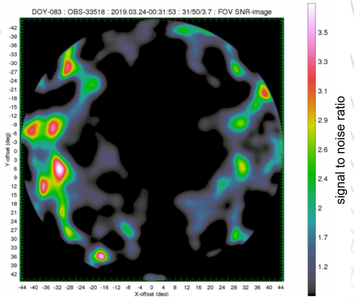
In contrast with the first ASIM TEB (180916, **[4]**)

- Softer spectrum ? *HR(190324) = 0.70, HR(180916) = 0.79* (threshold of 650 keV)
- *511 keV line not as clear* (HR = hardness ratio = ratio of number of counts above below threshold)
- Other interpretations are also possible (relative scaling is arbitrary)
- Instrument calibration to be re-checked carefully, but should be OK *a priori*
- **Physical explanation ?**
  - Evidence of *non-fullly-developped-RREA TGF*? (e.g. originated in inhomogeneous fields at leader tips with potential drops < 300 MV **[5]**)
  - TGF generated deeper in the atmosphere ?
    Incoming angle to ASIM (i.e. different obstacles) ?



- Spectrum resolved down to 50 keV for the first time (to our knowledge)
  (In principle Fermi-GBM's NaI detectors could also detected this energy range, but not published to our knowledge)
- Fit with RREA model fits OK for both LED and HED. Non-full-RREA models to be checked next.

Direction of the incoming electron beam (LED)



- Preferential direction
- Should be southwards, but not verified yet.

Preliminary conclusions / pending questions

- First TEB event detected by ASIM with both LED (50-370 keV) and HED (400 keV - >~30 MeV)
- First spectrum recorded down to 50 keV, fits expectations overall
  - consistent with RREA model simulations.
- First rough *measurement* of the incoming direction of the electrons (to our knowledge) using LED "imaging". To be verified.
- Problems to be solved:
  - 511 keV line weaker to previous event (180916)
  - "softness" compared to previous event (180916)

  → Non-fully-developped RREA model ? (e.g. leader)
  → Geometrical ?

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Acknowledgments

This study was supported by the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC grant agreement n. 320839 and the Research Council of Norway under contracts 208028/F50 and 223252/F50 (CoE). It has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement SAINT 722337. ASIM is a mission of ESA's SciSpace Programme for scientific utilization of the ISS and non-ISS space exploration platforms and space environment analogues. ASIM was funded through the ESA ELIPS program, through contracts with TERMA and Danish Technical University (DTU) in Denmark, University of Bergen (UB) in Norway and University of Valencia (UV) in Spain. Additional funding was supported by the ESA PRODEX contracts PEA 4000105639 and 4000111397 to DTU and ESA PRODEX contract 4000102100 and by Norwegian Research Council to UB.The ASIM Science Data Centre (ASDC) at DTU is supported by PRODEX contract PEA 4000115884 and by PRODEX contract PEA 4000123438 at UB. The ASIM Science Data Centre and data analysis activities at the UV are supported by the MINECO Research Grants ESP2015- 69909-C5-1-R and ESP2017-86263-C4-1-R. We thank Vaisala for the use of their data.