Observation of Elves with the Fluorescence Detectors of the Pierre Auger Observatory

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Electrodynamic coupling between electromagnetic fields produced by lightning discharges and the lower ionosphere.

Several observed phenomena, including various transient luminous events, such as Sprites and Elves.

**Elves**

Optical flashes produced by heating, ionization, and subsequent optical emissions.

They are due to intense electromagnetic pulses (EMPs) launched by cloud-to-ground lightning strokes.

- Confined to 80-95 km altitudes (*D layer of the ionosphere*)
- They extend laterally up to 600 km
- Duration: < 1 ms
Elves: First Observations

First clear observation by using a high speed photometer pointed at altitudes above those of sprites


Fly’s Eye and PIPER

They adopted linear arrays of photometers with a resolution of ~40 μs ⇒ study of the lateral expansion.

Data from space

ISUAL/Formosat-2 mission observed that elves develop on oceans ten times more frequently than on land

http://www-star.stanford.edu/~vlf
The main source of diffused UV background in clear dark nights is the airglow layer, located in the lower ionosphere.

The Fluorescence Detector (FD) comprises four observation sites, each with six independent telescopes (FOV of $30^\circ \times 30^\circ$)

**FD camera:** 22 × 20 hexagonal PMTs

**Wavelength range:** 300 – 420 nm

**Time resolution:** 100 ns
Observations – Event at GPS sec: 860806213

0 < t < 35 µs

35 µs < t < 40 µs

40 µs < t < 50 µs

50 µs < t < 75 µs
Photon Time Distributions

GPS sec: 800414142

GPS sec: 860806213

GPS sec: 861081389

ış Photon counts obtained from the sum of all photomultiplier ADC traces.

Additional information from the Second Level Trigger log files:

- events last much longer than 70 μs
- they are detected in adjacent FD bays or even in other telescope stations
Optical emission takes place at 80-95 km altitudes.

EMP source confined inside the troposphere.

Signal time evolution described by the intersection of a **sphere** (the D region) with **ellipsoids** with foci $O$ and $S$.

**First light** when the ellipsoid is **tangent** to the sphere.

**Strong constraints on the location of the EMP source.**
Each trace is formed by **1000 time bins of 100 ns** each.

Signal bounds found by maximizing the SNR.

**The signal is then smoothed** (2.1 μs running average).

**Pulse start** set at **5σ** above the noise.
Results

Interpolated 3D curve representing the time of arrival of photons at the FD diaphragm.

Best fit compared to real data for the column and row passing through the centre of the event.
Results and Crosschecks

Differences between measured pulse start times and simulated ones are confined within 2 μs, with the exception of one pixel which recorded a trace delayed by 7 μs.

Presence of a large cloud perturbation seen by GOES in the same region.

Very good agreement with WWLLN data (lightning pulse in coincidence)
The fluorescence detector of the Pierre Auger Observatory may represent an interesting opportunity to study the elve evolution with an unprecedented time resolution.

It is necessary to design a dedicated software trigger in order to transform the FD in an efficient elve detector.

The limitation of the 100 μs time window can be overcome by reading 10 consecutive time frames when an elve type event is identified.
Extra slides
Other Observations

GPS sec: 800414142

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