The relevance of fluorescence radiation in Cherenkov telescopes

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26th E+CRS / 35th RCRC  Barnaul - Belokurikha - Altai Mountains  (July 2018)
Outline

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Motivation

Do Č-telescopes see the atmospheric fluorescence of the shower?

Spectral range: 300 – 450 nm

De-excitation of N₂ states

Fluorescence and Č-photons arrive simultaneously

Radiative lifetime ≈ 40ns (N₂⁺: B²Σ⁺u); ≈ 60ns (N₂: C³Πu)
Collisional quenching -> effective lifetime < 3ns.
Motivation

Is fluorescence expected to be a small contribution?

- Fluorescence is less efficient than Cherenkov
  1 GeV electron near ground generates $\approx 30$ Č-photons/m
  but only $\approx 4$ f-photons/m

- Č-light is directional, fluorescence is isotropic

YES
It is
Motivation

Should fluorescence light be neglected in Č-telescopes?

We have developed an algorithm to simulate fluorescence emission in CORSIKA (cross-checked with a numerical model).

.... studied typical cases:

- Imaging air-Cherenkov telescopes IACTs (e.g., CTA, LHAASO)
- Arrays of wide angle Cherenkov detectors WACDs (e.g., Tunka, HiScore)

Our answer is: NOT ALWAYS

In some cases the contamination can be significant
Implementation of fluorescence in CORSIKA

Similar to that of Cherenkov photons

bunches of Č-photons in each sub-step
Subroutine CERENK

bunches of f-photons in different sub-steps
Subroutine FLUOR

Electron

Electron

Č-bunches

Not to scale

Not to scale

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Implementation of fluorescence in CORSIKA

Evaluation of the fluorescence light

\[
\frac{dN_\gamma}{dX} = Y(P, T, h) \frac{dE_{\text{dep}}}{dX}
\]

**Fluorescence yield** (photons / MeV)

Deposited energy

Reference value: yield of the 337 nm band

\[
Y_{337\text{nm}} (800 \text{ hPa, } 293 \text{ K}) = 7.04 \pm 0.24 \text{ ph/MeV}
\]

Dependent on atmospheric parameters

**Energy deposit in CORSIKA (key point):**

- Continuous ionization energy losses in each transportation step
- Local energy deposited by untracked particles (i.e., E cuts and upwards angles)
- Some marginal energy contributions not included yet

\[< 1\% \text{ in EM showers} \]
\[< 3\% \text{ in hadronic showers} \]
Implementation of fluorescence in CORSIKA

Fluorescence vs. Cherenkov (an example)

10 TeV vertical γ-ray showers
Atmospheric depth: 800 gcm$^{-2}$
Fluorescence contamination in Č-telescopes

\[ R_{FC} = \frac{\text{Fluorescence photon density}}{\text{Cherenkov photon density}} \]

Fluorescence contamination \( R_{FC} \) evaluated at three telescope-shower distances \( x = 500, 750, 1000 \) m

- Strong dependence on the FoV
- Weak dependence on the shower energy
Fluorescence contamination in Č-telescopes

**IACTs**

FoV = 10° on-axis

FoV = 10° off-axis

**γ-ray**

EAS

FoV

800 gcm$^{-2}$

**Fluorescence contamination**

- Zenith angle [deg]
- Off-axis angle [deg]

- 100 TeV
- θ = 20°
Fluorescence contamination in Č-telescopes

Arrays of WACDs

\[ \text{FoV} = 60^\circ \text{ vertical observation} \]

- \( \theta = 20^\circ \)
- \( \text{FoV} \) = 60°
- \( \text{Energy of primary } \gamma \text{ ray [TeV]} \)
- \( \text{Fluorescence contamination} \)
- \( \theta = 20^\circ \)
- \( x = 20^\circ \)
- \( E = 100 \text{ TeV} \)

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Conclusions

An algorithm for fluorescence emission has been implemented in CORSIKA

Fluorescence contamination in IACTs:

≈ 0.1% within the light pool (r < 200m). Irrelevant in low energy (<TeV) observations.
≈1% (500m), >5% (1000m). **Non-negligible in the TeV - PeV** region using arrays of IACTs collecting signals at large core distances.

- Nearly independent of energy.
- It might increase in off-axis observations.
- Negligible for very inclined showers (x<1000m). Elongated light pool.

Fluorescence contamination in arrays of WACDs:

Strong effect, in particular at high energy.
In the PeV region the signals can contain up to 45% of fluorescence \((R_{FC} = 0.8)\)

Trigger requirement:

\[
\Delta t = \text{transit time} - \text{camera FoV}
\]

\[
\Delta t / n_{\text{PMT}} = \text{transit time} - \text{pixel FoV} \quad (n_{\text{PMT}} \approx 40)
\]

\(n_{\text{PMT}}\) number of PMTs along a diameter
IACTs could work in **fluorescence** mode as far as the trigger is adapted to the corresponding time window.

**Geometrical estimates:**

- A time window of tens of μs would allow recording full tracks of showers at tens of km distances.
- Time windows of about 1 μs could be enough to reach a few km distances (full track at $\Psi < 30^\circ$).
- At smaller shower-telescope distance only a fraction of the track can be recorded by a single telescope. Nonetheless, an array of IACTs in observation modes with large FoV can record the whole track and with **very high transversal resolution**.
Backup slides
Implementation of fluorescence in CORSIKA

Cross-check with a numerical algorithm

Algorithm:

- One dimension shower development of deposited energy
  - analytical
  - generated by a MC algorithm
- Number of photons at ground from fluorescence model and geometry
- No statistical fluctuations

- Very good agreement between CORSIKA implementation and algorithm.
- Discrepancies at small and large radial distances attributed to the 1D approximation.

Very useful when limited by computing resources
Transversal distribution of fluorescence in IACTs

IACT camera

Fluorescence telescope (Auger-like) camera

Hi-res. transversal distribution

Longitudinal development

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