The relevance of fluorescence radiation in Cherenkov telescopes

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Abstract

Cherenkov telescopes, one of the main techniques used in very-high-energy gamma-ray Astrophysics, are also sensitive to atmospheric fluorescence produced by extensive air showers. However, this contribution is currently not considered in the reconstruction and analysis chains of imaging air Cherenkov telescopes (IACTs) and wide-angle Cherenkov detectors (WACDs). The emission and tracking of atmospheric fluorescence photons have been implemented in the CORSIKA code, a program for detailed simulation of extensive air showers, aiming to evaluate the fluorescence contamination to both types of telescopes. We are also exploring the possibility of using these same telescopes to detect fluorescence radiation. This technique would be complementary to the detection of Cherenkov light and it would allow us to reach even higher energies, out of the scope of any current technique.

1. Motivation

Extensive air showers (EASs) initiated by high-energy cosmic-ray particles produce both **Cherenkov** and **fluorescence** light (de-excitation of N_2 states), which **are indistinguishable** at the telescope level:

- Same spectral range ~ 300-500 nm.
- Similar arrival times ~ few ns.

Cherenkov telescopes are **also sensitive to fluorescence radiation** which is **expected to be a small contribution** compared with Cherenkov light:

- Fluorescence is less efficient than Cherenkov.
- Fluorescence emission is isotropic, while Cherenkov light is directional.

Should fluorescence light be neglected in Cherenkov telescopes?

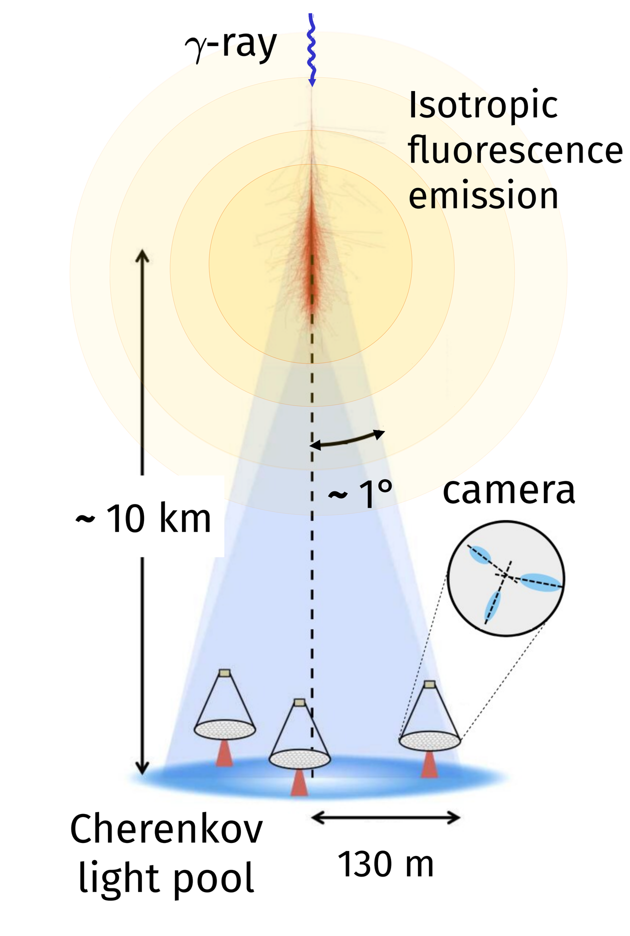

Fig. 1: Sketch of the Cherenkov and fluorescence light emission in EASs.

2. Tools: Monte Carlo simulations

- **Implementation of the fluorescence light emission** [1] in the EAS simulation program **CORSIKA** [2], **similarly to the existing Cherenkov subroutine.**
- Charged particles (mostly $e^{\pm}$) are transported straightly between each interaction point (Fig. 2) → **energy deposited** due to the continuous ionization energy loss.
- The **number of fluorescence photons** emitted in each step is proportional to the energy deposited in it and depends on the atmospheric conditions.
- Photons are equally **distributed in bunches**, emitted isotropically from each sub-step and transported to the observation level (Fig. 2).

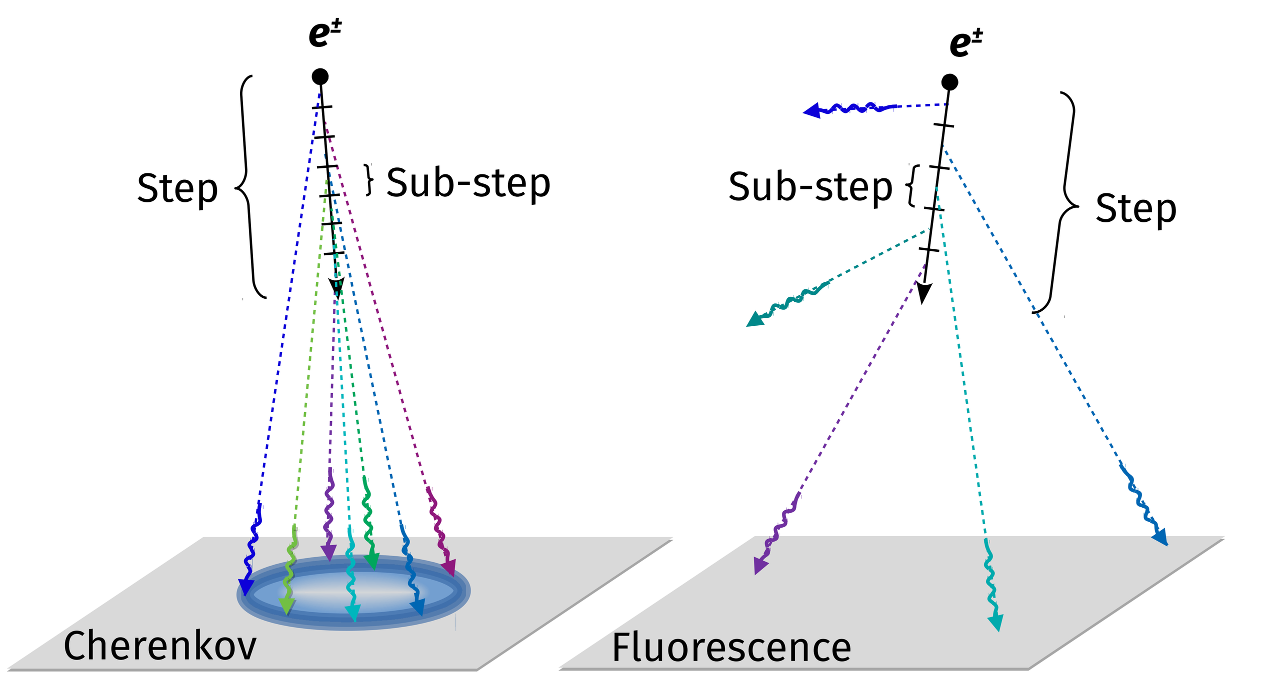

Fig. 2: Outline of the emission of Cherenkov and fluorescence photon bunches in each transportation step.

- First test: 2D distribution of Cherenkov and fluorescence light on ground.

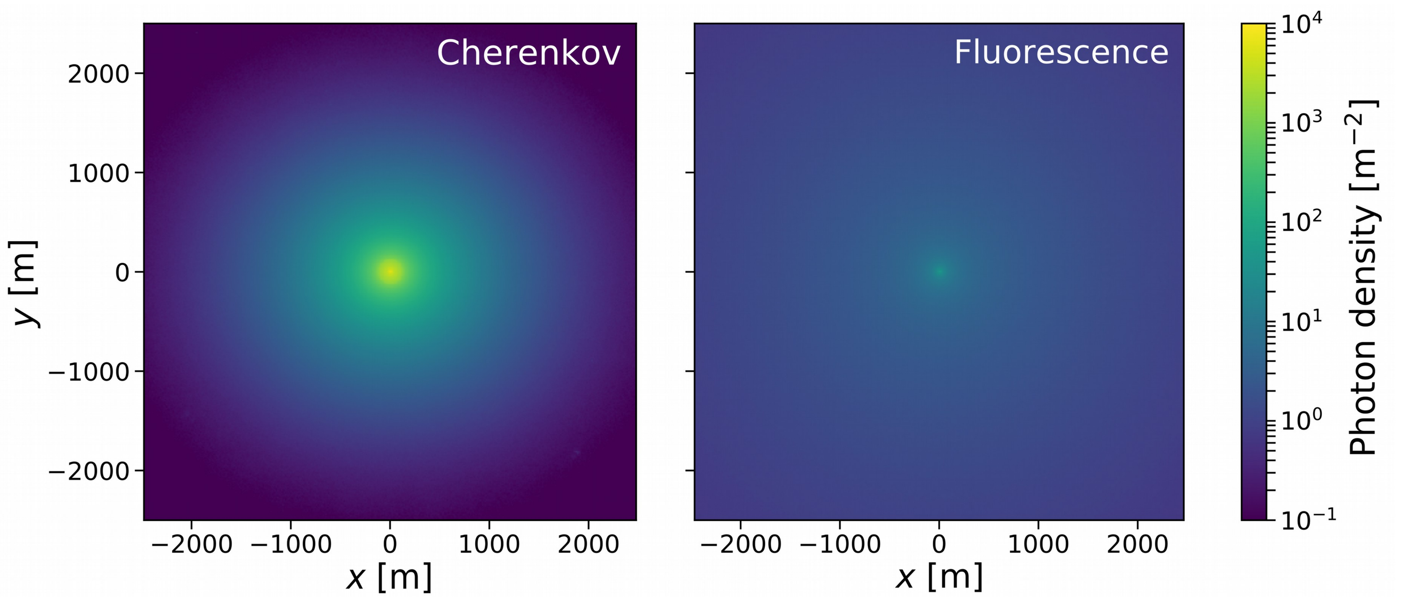

Fig. 3: Averaged 2D distributions of Cherenkov and fluorescence light on ground from 10 TeV γ-ray vertical showers.

- **MC production:** γ-ray showers in the energy range of 100 GeV – 1 PeV and zenith angles θ between 0° and 60°.

3. Results: fluorescence contamination in Cherenkov telescopes

- **Two observational techniques** with different geometry considered (Fig. 4):

Imaging air Cherenkov telescopes (IACTs):
- Narrow FoV ~ 1°-10°
- Point to the source
- Imaging telescopes

Wide-angle Cherenkov detectors (WACDs):
- Wide FoV ~ 60°
- Non-steerable devices
- Register air showers transversely

Fig. 4: Geometry of both Cherenkov techniques, IACTs (left) and WACDs (right), observing an air shower.

- **Different fluorescence contamination in each case.** Lateral profiles of Cherenkov and fluorescence light on ground: **relative fluorescence contribution increases with the distance to the shower** (Fig. 5).
- Evaluation of the **ratio of the fluorescence over Cherenkov light density (R_{FC}) on ground** at different impact parameters (x) as a function of the energy and zenith angle of the primary gamma ray [1].

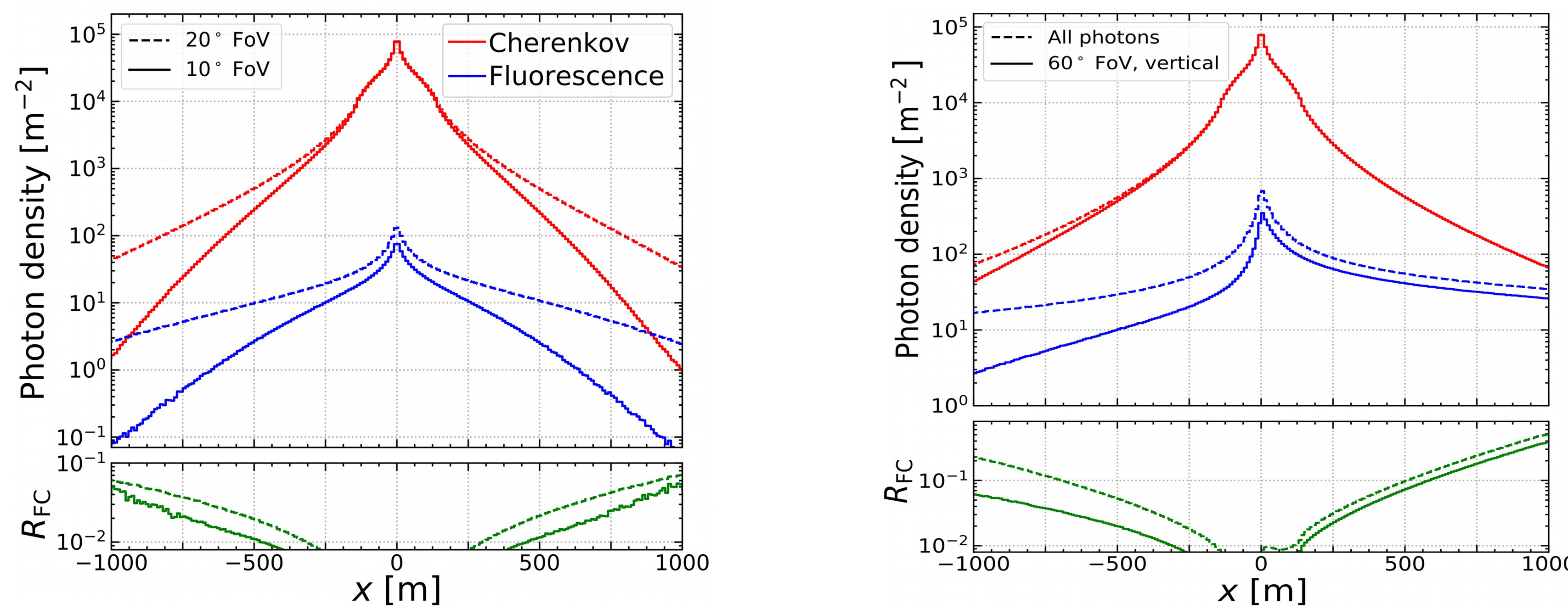

Fig. 5: Averaged lateral profiles of Cherenkov and fluorescence light on ground from 100 TeV γ-ray showers with a zenith angle of 20° for both scenarios IACTs (left) and WACDs (right).

4. Cherenkov telescopes in fluorescence mode

Work in progress

- If showers are registered transversely with IACTs (Fig. 6):

Fluorescence signal $\gtrsim$ Cherenkov signal

- Arrays of IACTs (e.g. CTA) **could be used simultaneously as fluorescence detectors** provided the trigger is adapted to the corresponding time window (~ 1 – 10 μs) [3]:
  - → Detailed MC study simulating the fluorescence light through the telescopes using the software `sim_telarray` [4] needed.

Goals:

- Larger effective areas for VHE gamma rays → reach higher energies still not explored by any technique.
- Detection of cosmic-rays showers with unprecedented angular resolution in the radial distribution along the whole longitudinal development.

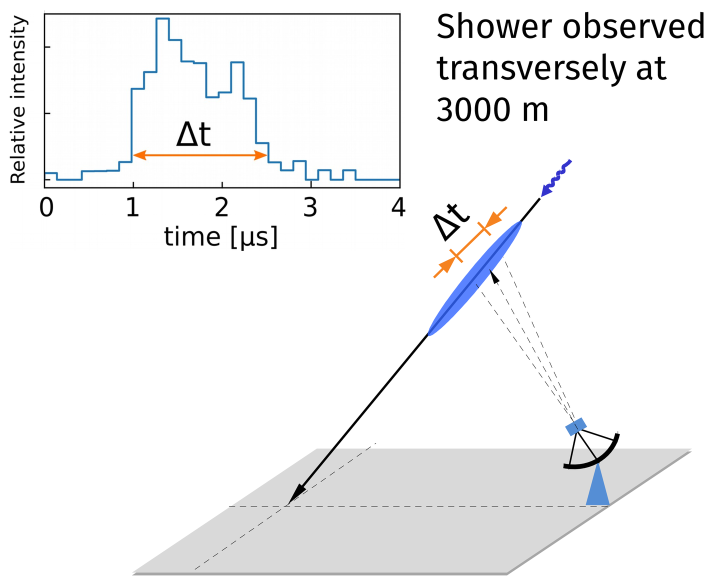

Fig. 6: Sketch of an IACT operating in fluorescence mode and transit time of the fluorescence signal along the camera.

5. Conclusions and outlook

1. **Fluorescence contamination is not always negligible**:
   - IACTs → ~ 5% at large core distances (≈ 1000 m) and nearly independent with the energy.
   - WACDs → can be very significant (~ 45%) in the PeV region.
2. Possibility of using arrays of **IACTs as fluorescence detectors** → extend telescopes performance for VHE gamma-ray Astrophysics.
3. Further studies including telescope simulations needed → more accurate fluorescence evaluation.

References

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