Large Sized Telescope

Impact of Calima on Atmospheric Transmission and on the Performance of the CTAO LST System at ORM, La Palma

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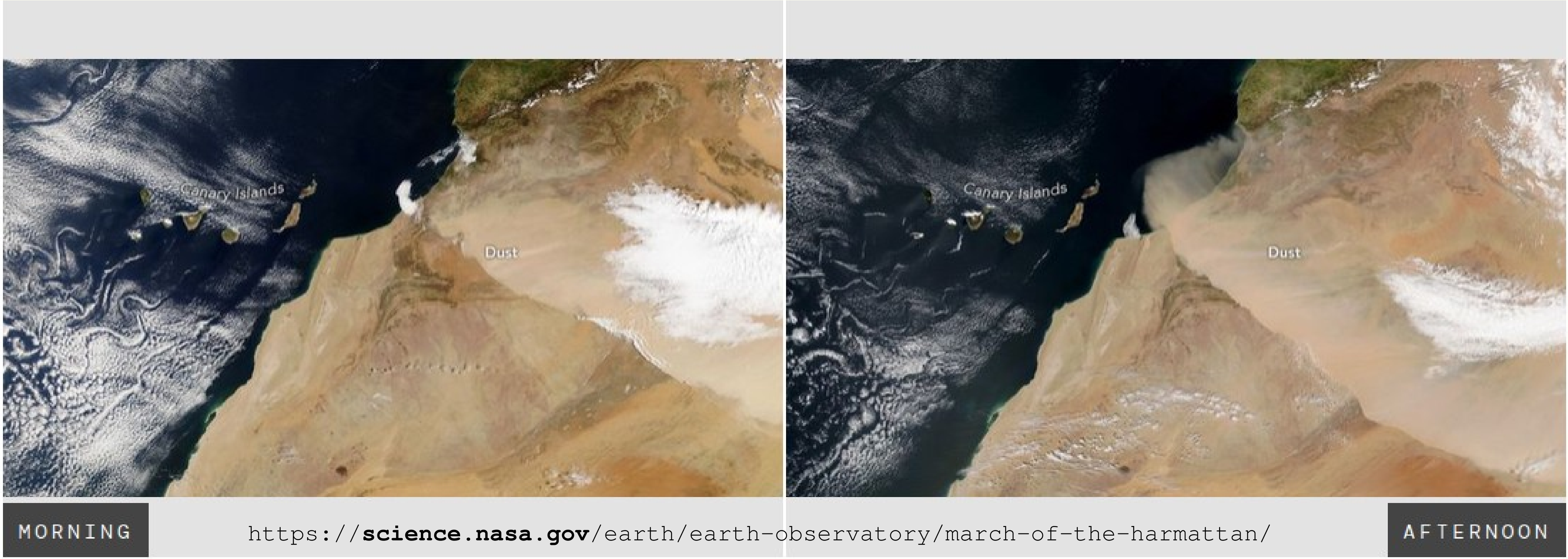
Saharan dust (calima) spreads across northwestern Africa on **30 March 2026**. The morning image was acquired by the MODIS instrument aboard the Terra satellite, and the afternoon image by VIIRS aboard NOAA-21.



https://**science.nasa.gov**/earth/earth-observatory/march-of-the-harmattan/

Acknowledgements

We gratefully acknowledge **Storm Therese**, whose passage across the Canary Islands in March 2026, although meteorologically inconvenient, gave us unexpected additional time to advance this calima study.

Motivation

- This work extends a previous study of the impact of clouds on CTAO observations presented in Mario Pecimotika’s PhD thesis.

- Here, instead of clouds, we focus on episodes in which Saharan dust, locally known as **calima**, is transported over the Atlantic and reaches the atmosphere above La Palma.

- Calima is frequently present above ORM at approximately 2200 m a.s.l.
  Working concentration benchmarks used in this study:
  – weak calima: $< 10\ \mu g/m^3$
  – moderate calima: $\sim 25\ \mu g/m^3$
  – strong calima: $> 60\ \mu g/m^3$

- Currently, no quantitative criteria exist for handling calima-affected observations.

- A rough operational rule of thumb currently used in practice is:
  – $<10\ \mu g/m^3$: ignore the effect
  – $>10\ \mu g/m^3$: reject the affected data

Objectives

1. To **determine the dust-concentration threshold** below which calima can be neglected.

2. To **quantify the impact of calima** on the performance and spectral reconstruction of the four-LST system.

3. To **provide the basis for future correction methods** and adaptive scheduling.

Simulations I
(atmospheric transmission in the presence of calima)

Atmospheric transmission was calculated using
MODTRAN 5.2.2 on DESY servers.

MODTRAN (MODerate resolution atmospheric TRANsmission) is a **radiative-transfer code** that models the propagation of electromagnetic radiation through the Earth’s atmosphere.

Many thanks to DESY, especially to **Gernot Maier**, for providing access to its computing resources and MODTRAN.


MODTRAN®5.2.0.0 USER'S MANUAL

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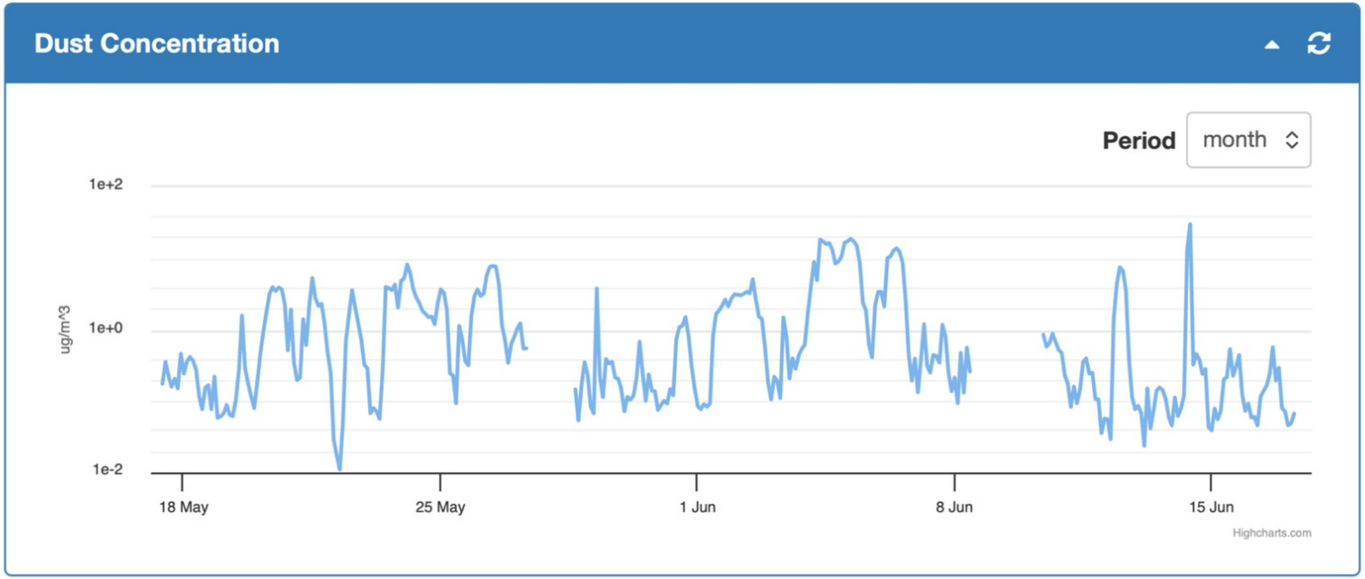
Atmospheric model



- The TNG dust monitor provides the **local dust mass concentration**, C_m in μg/m^3, at telescope altitude, approximately 2.2 km a.s.l.

Atmospheric model

- From C_m, we estimate the aerosol extinction coefficient at 550 nm, represented by the MODTRAN variable *AHAZE*, using an adopted **mineral-dust mass extinction efficiency** of k_{ext} **= 0.8 m^2/g** (it is a provisional bulk approximation and depends on the particle-size distribution and mineral composition)

- For C_m expressed in $\mu g m^{-3}$: $AHAZE(z)$ $[km^{-1}] = 10^{-3} \cdot k_{ext}$ $[m^2 g^{-1}] \cdot C_m(z)$ $[\mu g\ m^{-3}]$

- *AHAZE* represents total aerosol extinction, including scattering and absorption. The differential aerosol optical depth is $d\tau_{550} \approx AHAZE(z)$ $[km^{-1}] \cdot ds$ $[km]$

- Then optical depth: $\Delta\tau_{550} = \int AHAZE(z) \cdot ds$

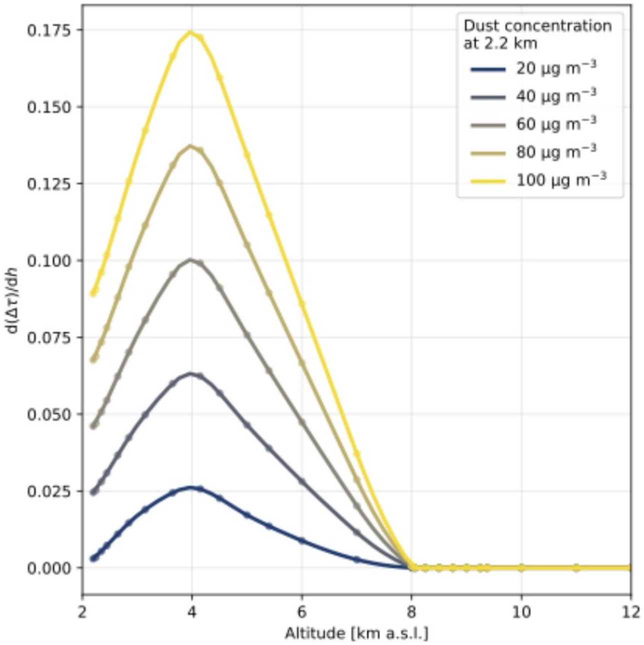
- And transparency: $T_{550} = \exp(-\Delta\tau_{550})$

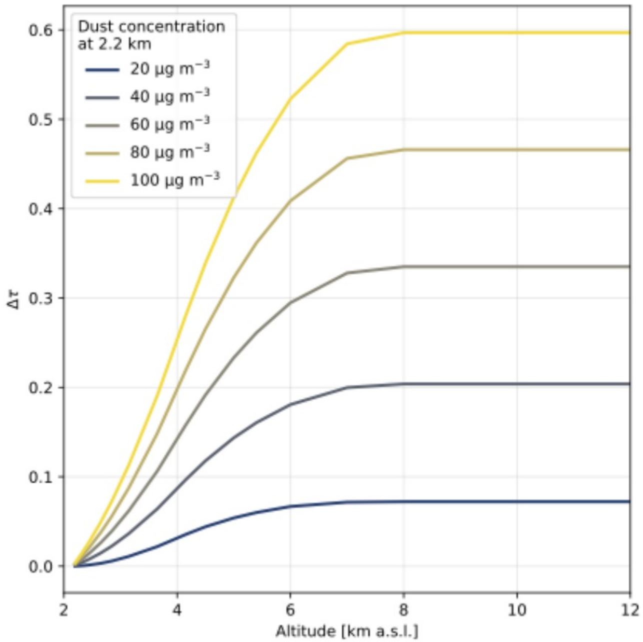
Atmospheric model

- Calima was modelled using a piecewise-linear vertical dust profile extending from sea level to 8 km a.s.l., with a maximum at 4 km a.s.l.

- Although the profile is defined from sea level, only the portion above the telescope altitude contributes to the downward Cherenkov-light transmission calculated for the telescopes.

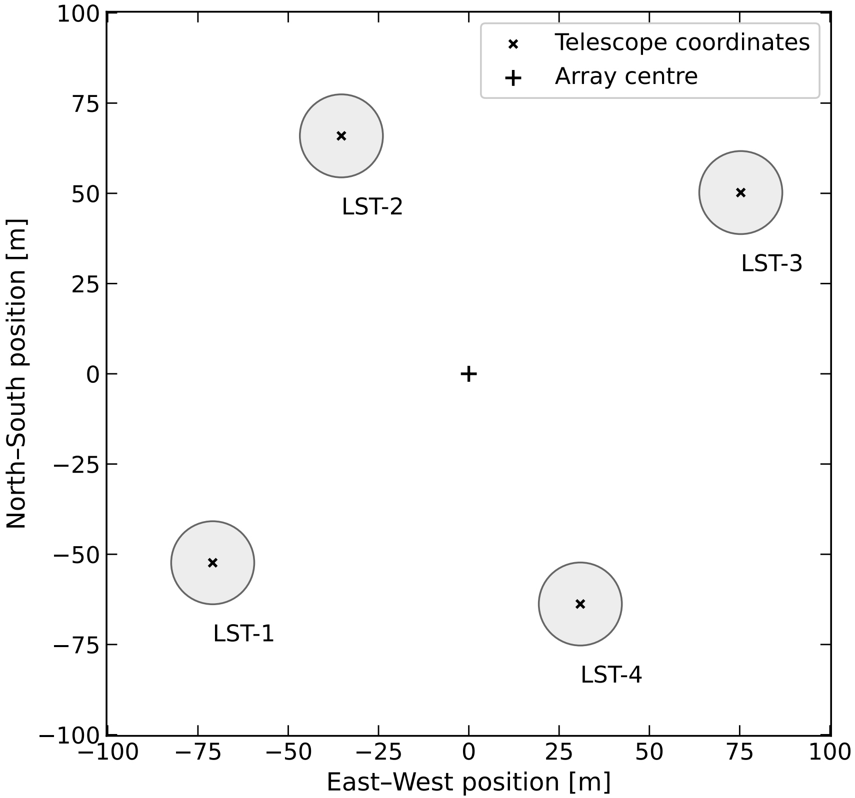
Dust concentration at 2.2 km [μg/m³]	Dust-layer transmission **at 550 nm**
20	0.93
40	0.82
60	0.72
80	0.63
100	0.55





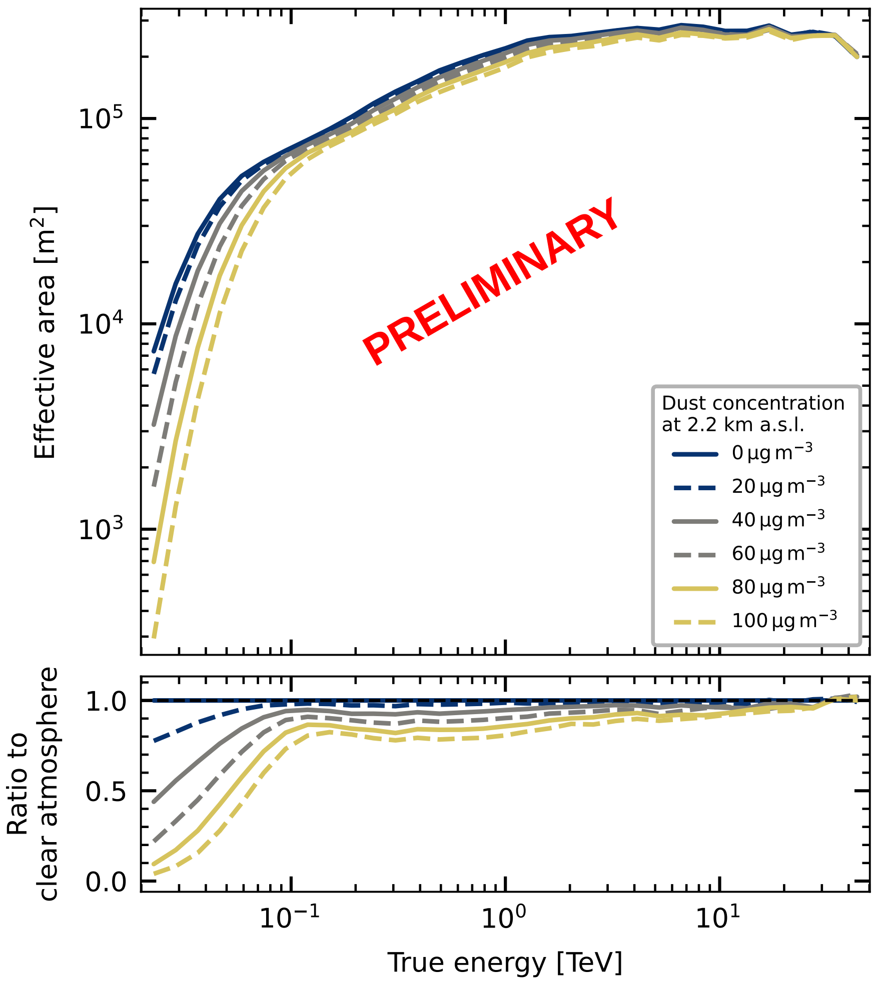
Simulations II
(Cherenkov light propagation and instrument response)

- Air showers were simulated with **CORSIKA 7.8**, and the detector response with `sim_telarray` using the Prod6 configuration
- Four-LST array configuration
- Zenith angle: $20°$; azimuth: $180°$
- Primary particles: gamma rays, protons, and electrons
- The simulated data were analysed with `magic-cta-pipe`



Effective area

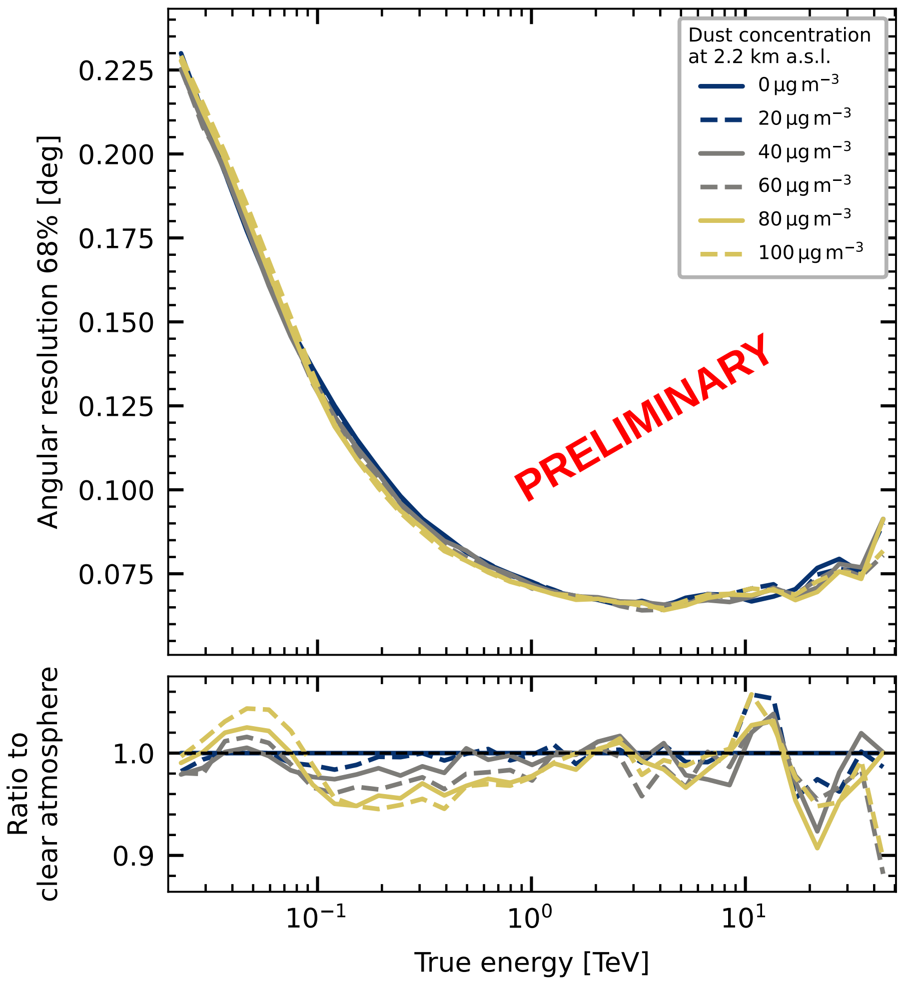
- The effective area decreases systematically with increasing dust concentration
  - Largest effect occurs below 0.1 TeV: for 100 μg/m³ the effective area is reduced by more than an order of magnitude
  - Above 1 TeV, the reduction remains below approximately 20%.
- Energy threshold:
  - 29 GeV (clear) → 56 GeV (100 μg/m³)
  - The energy threshold scales approximately inversely with the effective Cherenkov-light transmission



Angular resolution

- Atmospheric extinction mainly reduces image intensity, while geometrical image parameters are only weakly affected

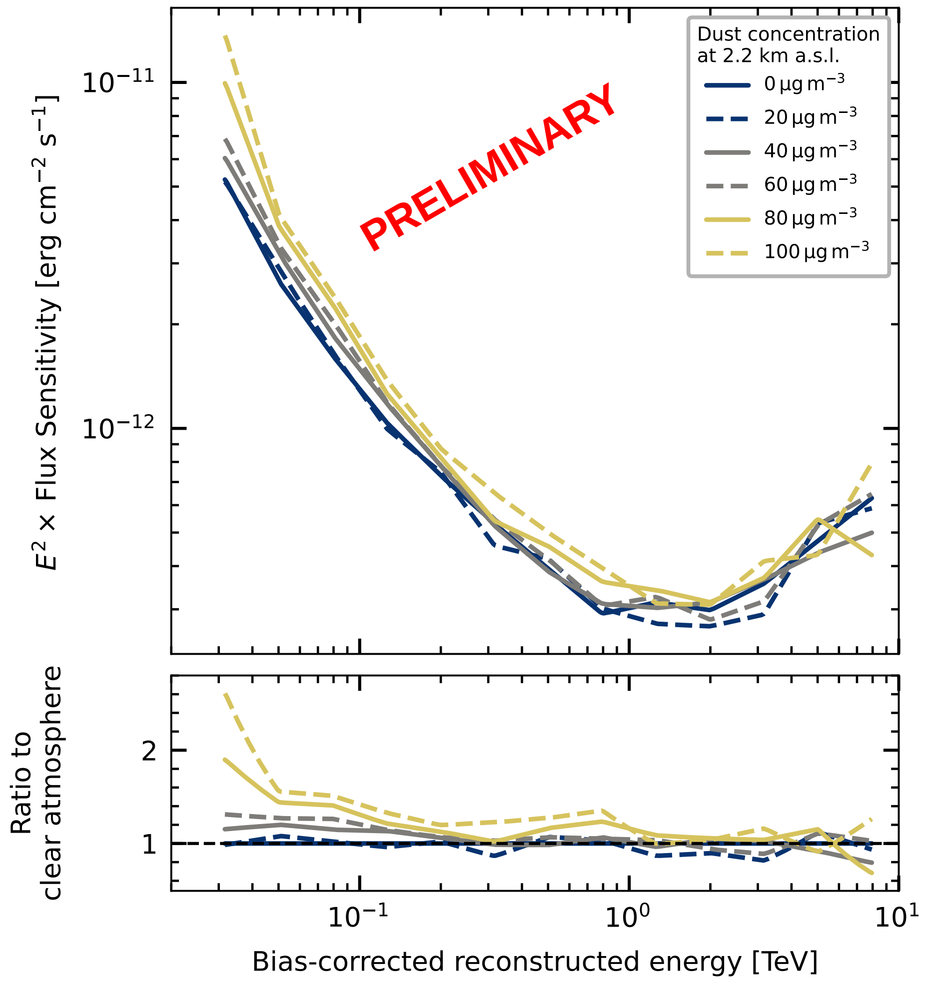
- Consequently, the angular resolution changes by only a few percent over most of the energy range, even under the strongest simulated calima conditions



Differential sensitivity

- After correcting for the energy bias, the remaining sensitivity degradation is primarily caused by the reduced effective area and increased energy threshold

- The largest degradation occurs close to the energy threshold
  - At approximately 30 GeV, the differential sensitivity for the 100 µg/m³ case is degraded by a factor greater than 2.5
  - Above approximately 0.5 TeV, the degradation is typically below 20%



Conclusions

- Calima acts primarily as an atmospheric attenuation layer, reducing the detected Cherenkov-light yield by up to 45%, while image geometry and angular resolution remain comparatively stable

- The strongest degradation of the LST performance occurs at low energies, where the effective area decreases and the energy threshold increases.

- Using standard clear-atmosphere MC simulations for calima-affected data introduces substantial systematic biases, including energy underestimation, spectral softening, and flux underestimation

- Calima-adapted MC simulations could largely restore the energy scale and spectral reconstruction accuracy