The ATLID laser beam observed by the cosmic ray observatories Pierre Auger (Argentina) and Telescope Array (USA)

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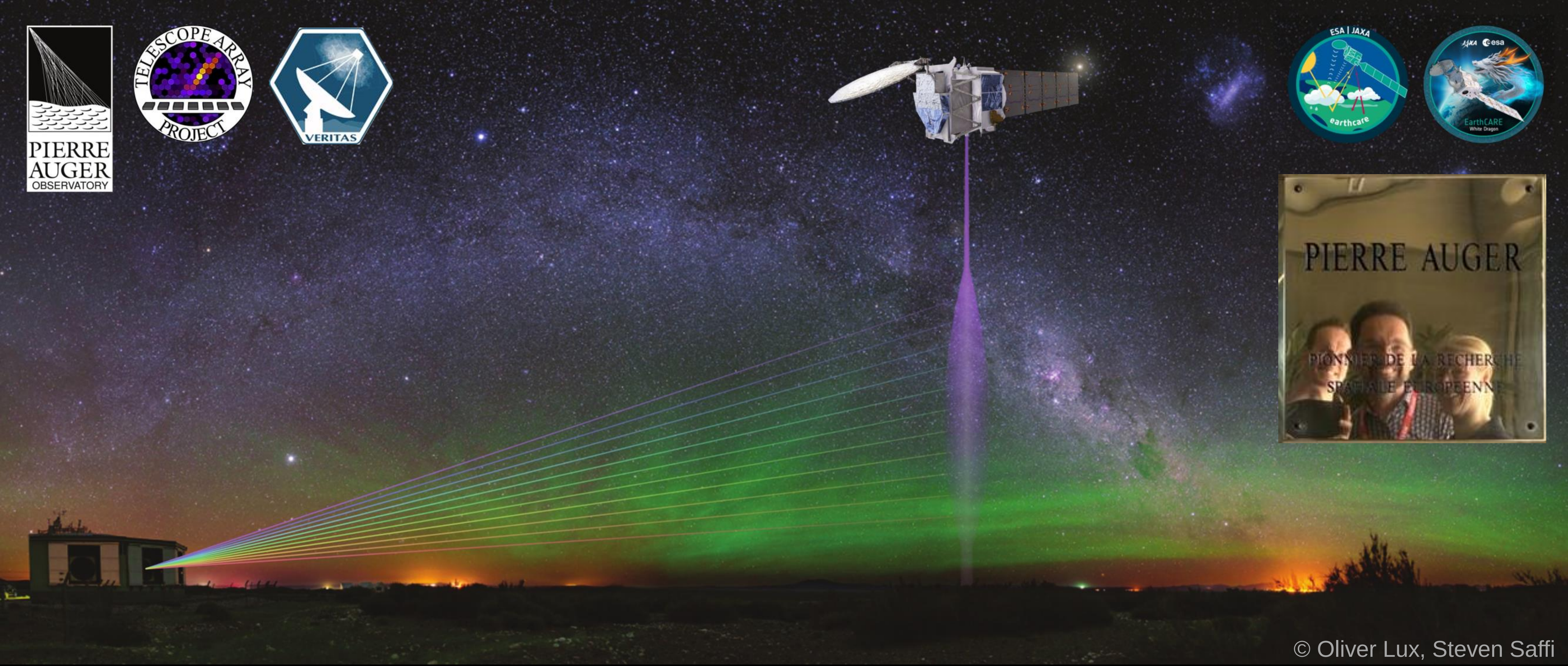
2nd ESA-JAXA EarthCARE In-Orbit Validation Workshop

17 – 20 March 2025 | ESA-ESRIN | Frascati (Rome), Italy

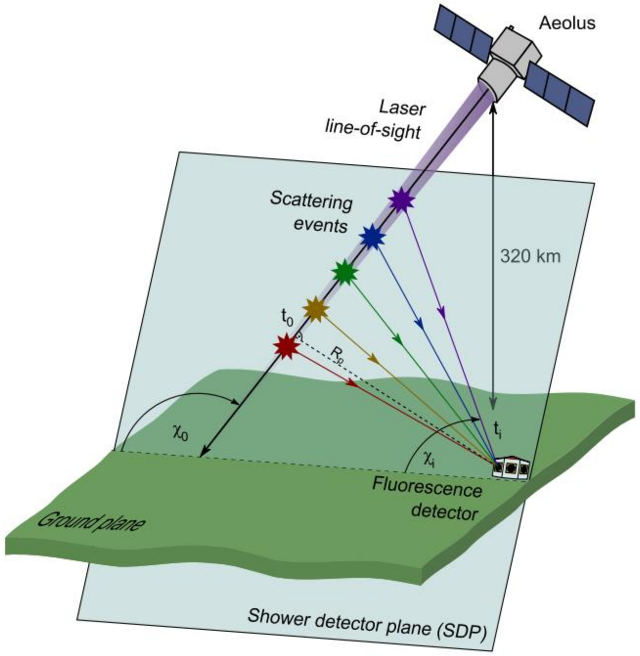


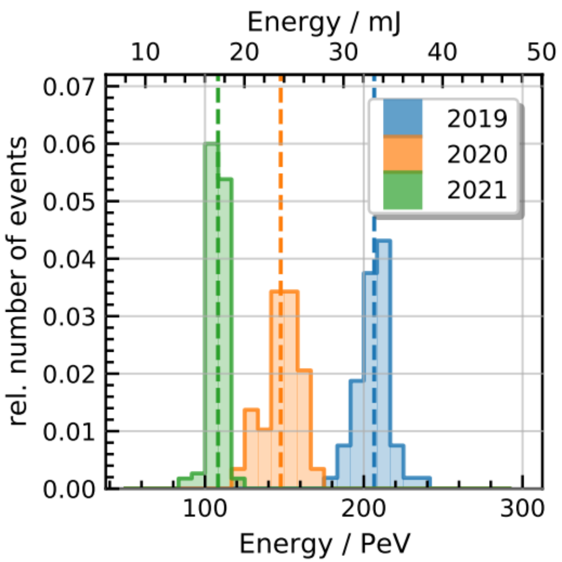
ATLID laser beam from EarthCARE is regularly measured at the Pierre Auger observatory and at the Telescope Array.

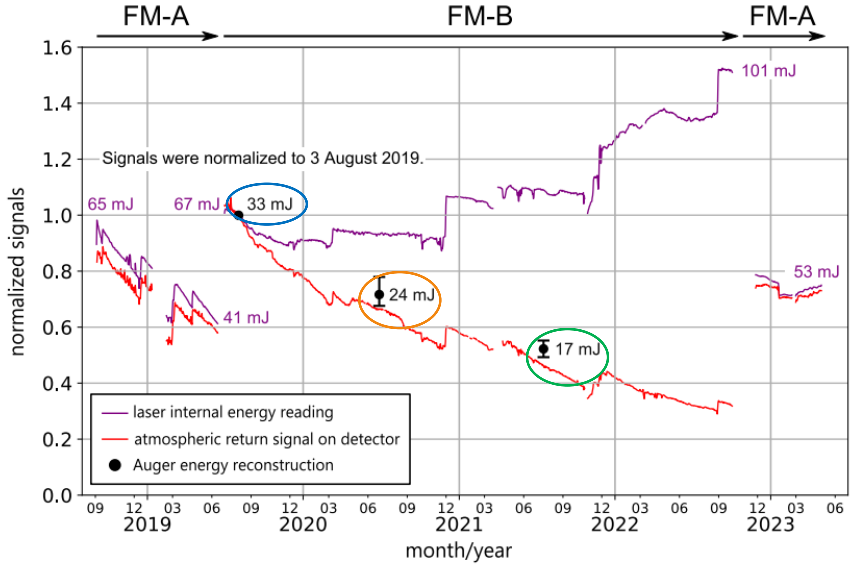
Both ground-sites will be used to determine the geolocation of each laser shot and its laser energy.

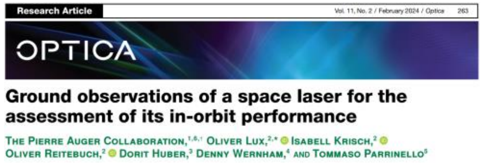
ATLID laser beam will be exploited for inter-calibration between the two observatories: ATLID as a “calibration star”.

Earth observation meets Astrophysics





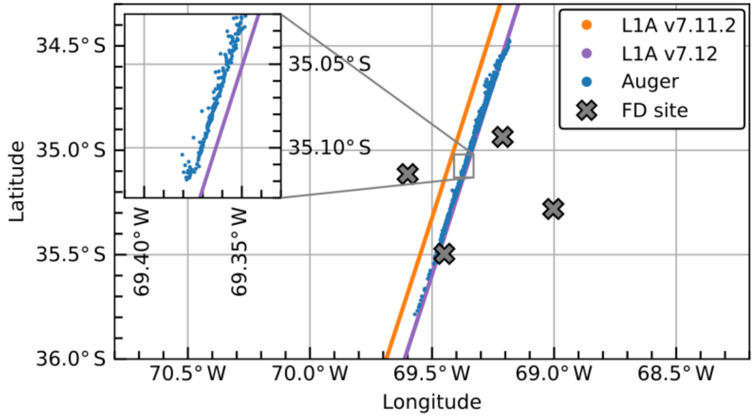



Research Article

OPTICA

Ground observations of a space laser for the assessment of its in-orbit performance

The Pierre Auger Collaboration, Oliver Lux, Isabell Krisch, Oliver Reitebuch, Dorit Huber, Denny Wernham, and Tommaso Parrinello



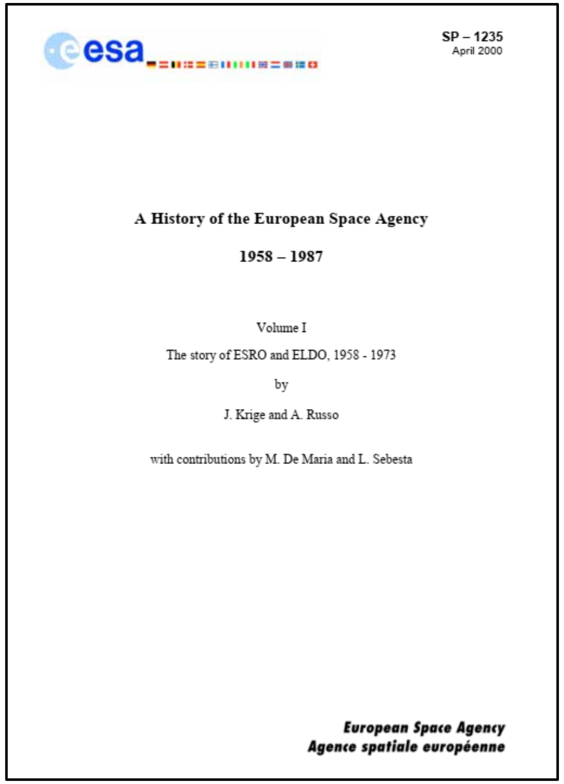
- **First measurements of a space-borne ultraviolet laser beam** by an Earth-based observatory designed to detect ultrahigh-energy cosmic rays - the Pierre Auger Observatory, Argentina.
- These observatories are used to detect fluorescence light in the UV from cosmic particle showers hitting N_2 molecules (about 280 nm to 430 nm).
- Ground-truth verification of the Aeolus laser ground track and pulse energy at the telescope output → support for root cause analysis regarding the loss in atmospheric return signal and decision to switch-back to first laser FM-A in 2022.

Pierre Auger (1899-1993) – Pioneer for ESA

Pierre Auger in 1935
Cosmic ray observations at Jungfraujoch in 1938

Pierre Auger memorial plaque @ ESRIN
photo: T. Parrinello (ESRIN)

Pierre Auger in 1960
1964-1967 First Director General
of ESRO – European Space
Research Organization



esa

SP – 1235
April 2000

A History of the European Space Agency

1958 – 1987

Volume I

The story of ESRO and ELDO, 1958 - 1973

by

J. Krige and A. Russo

with contributions by M. De Maria and L. Sebesta

European Space Agency
Agence spatiale européenne

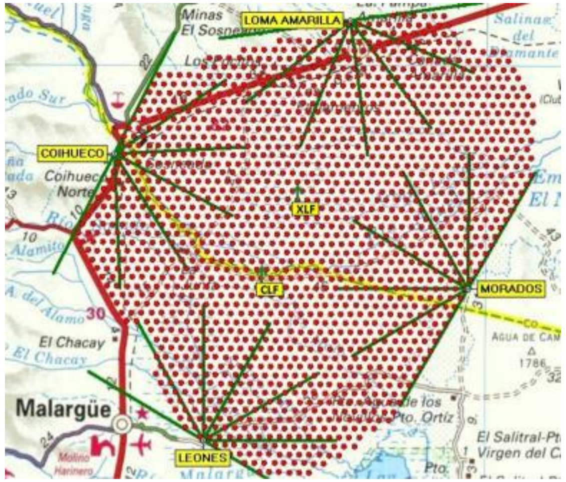
Observatories for ultra-high-energy cosmic rays

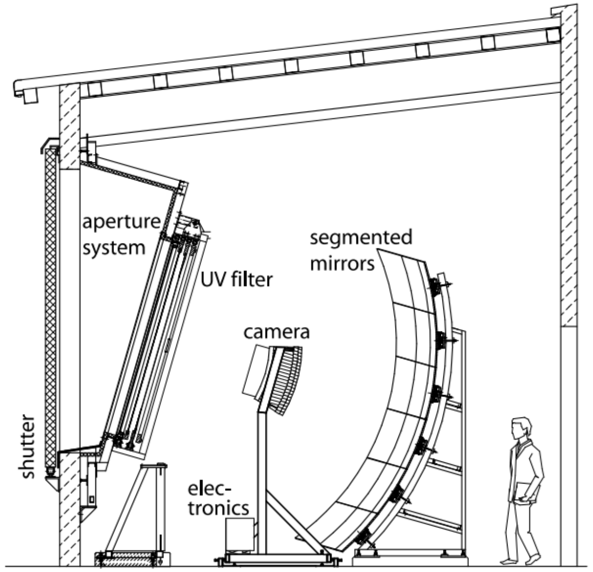
PIERRE AUGER OBSERVATORY

Pierre Auger Observatory
Argentina

- 4 fluorescence detector sites spaced by 40 km, with a total of 24 telescopes of 13 m^2, 3 telescopes at additional site (HEAT)
- 440 photomultiplier tubes (PMTs) per telescope
- Elevation coverage: 0° to 30°
- 1,660 surface detector tanks filled with 12 t of ultra-pure water covering an area of ≈3,000 km²

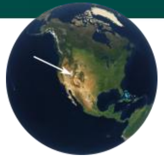
The Pierre Auger Collaboration, The Pierre Auger Cosmic Ray Observatory, Nucl. Instrum. Methods Phys. Res. A: (2015).





TELESCOPE ARRAY PROJECT

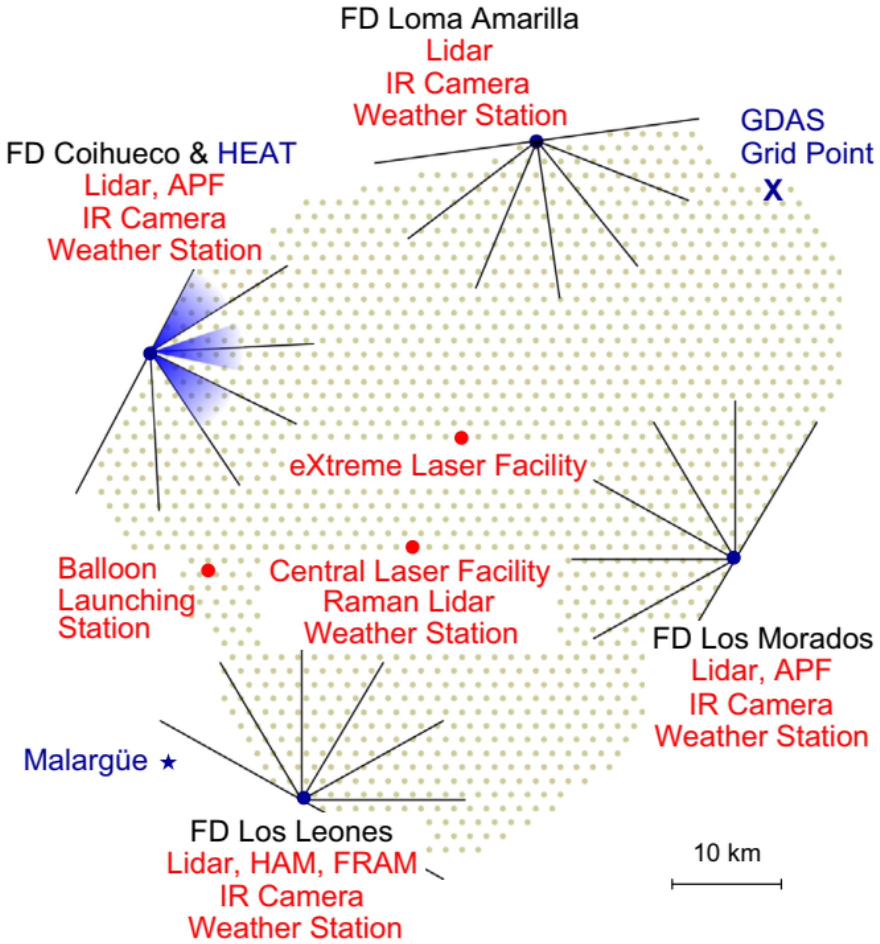
Telescope Array Project
Utah, USA



- 3 fluorescence detector sites on a 30 km triangle with a total of 38 telescopes
- 256 PMTs per telescope
- Elevation coverage: 3° to 33°
- 507 scintillator surface detectors on a square grid covering an area of about 700 km²

H. Tokuno et al., New air fluorescence detectors employed in the Telescope Array experiment, Nucl. Instrum. Methods Phys. Res. A (2012).

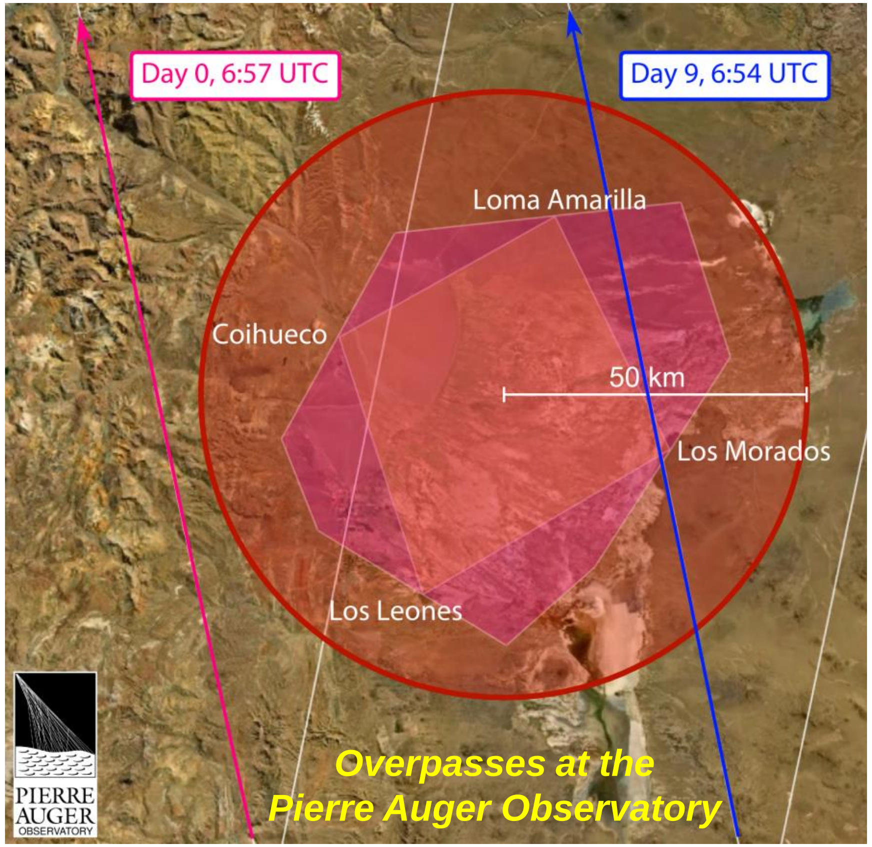
Atmospheric monitoring with lidars at Auger

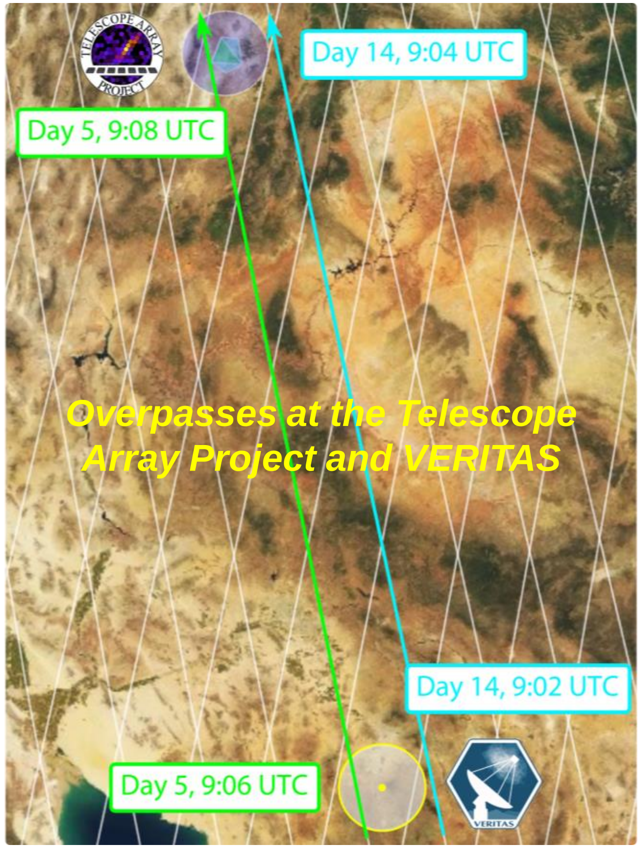


- Characterization of aerosol optical depth and aerosol phase function (APF) for the 4 fluorescence detectors (FD) telescope sites.
- Each telescope site (FD) is equipped with an **elastic backscatter lidar** (Nd:YLF @ 351 nm) **with scanner.**
- **Central laser facility (CLF) is equipped with a Raman lidar** since 2013 (tripled Nd:YAG @ 354.7 nm, 6 mJ, 100 Hz) with N_2 and H_2O channel, aerosol α and β – retrieval by INFN, La Aquila, Italy.
- Scattering from the eXtreme Laser Facility (XLF) and CLF lasers (tripled Nd:YAG @ 354.7 nm) are recorded by the 4 telescope sites (FD).

The Pierre Auger Collaboration, The Pierre Auger Cosmic Ray Observatory, Nucl. Instrum. Methods Phys. Res. A: 798, 172–213 (2015)
Atmospheric Monitoring for High Energy AstroParticle Detectors AtmoHEAD workshops; last in 2024: E. Avocone, V. Rinzi, L. Valore, INFN//La Aquila,.Italy
B. Keilhauer, Atmospheric Monitoring for Astroparticle Physics Observatories, Proc. 38th International Cosmic Ray Conference (ICRC2023)

EarthCARE overpasses during its 25-d repeat cycle



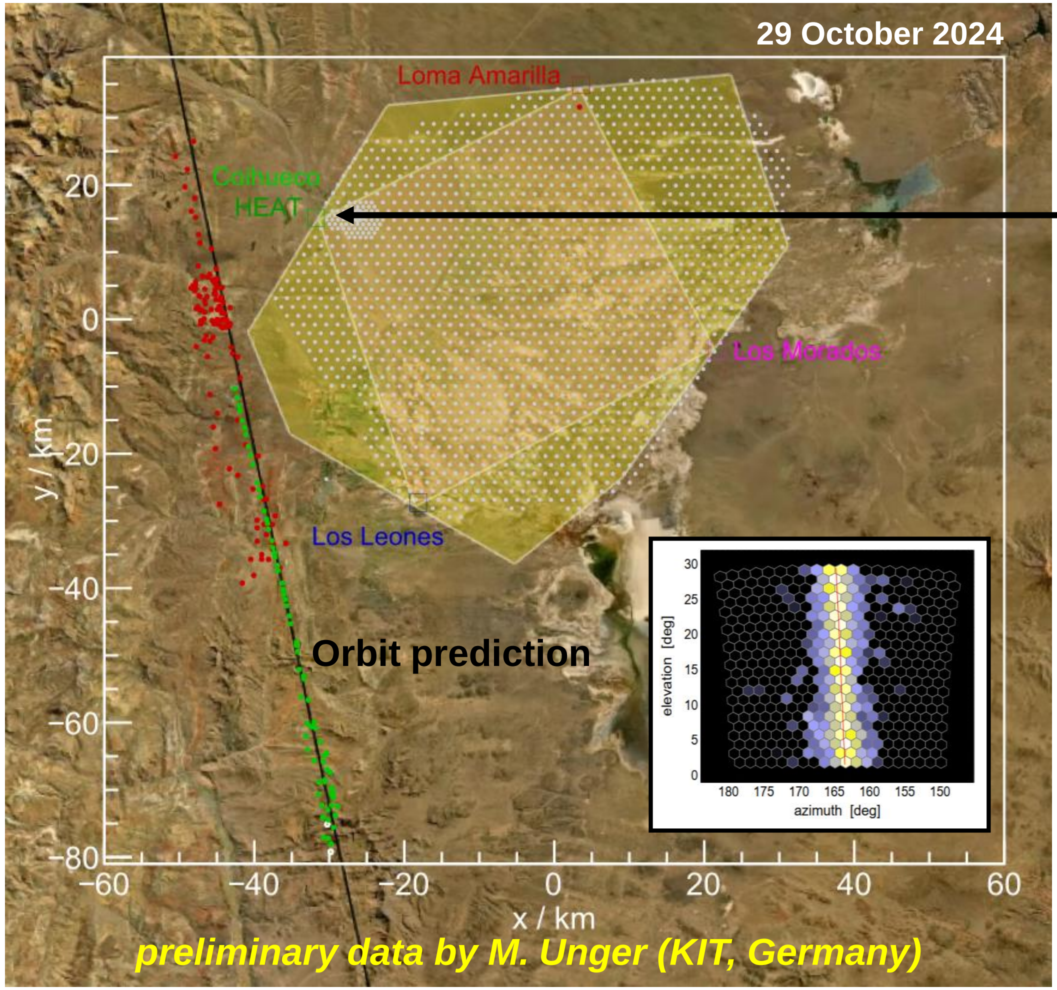


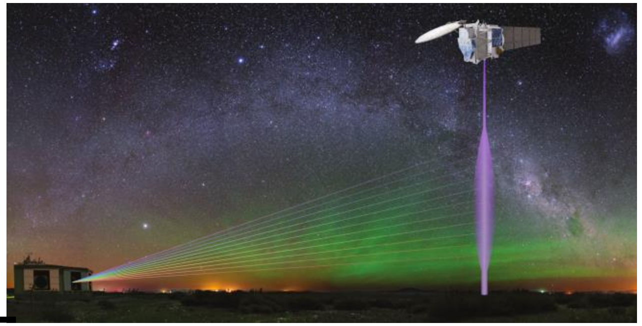
- **Each of the three observatories experiences two overpasses during each 25-day orbital repeat cycle of EarthCARE;** darkness for ascending orbits during complete year; Aeolus visibility was limited to May-August for Auger due to its dawn-dusk orbit.
- **The two overpasses of the Telescope Array and VERITAS occur within just two minutes**, as they are aligned along the same orbit.
- **Observation at VERITAS** (detection of γ-rays with 4 Cherenkov-telescopes) requires precise prediction of azimuth and elevation angles, since telescopes need to be accurately aligned due to the small field-of-view (3.5°).

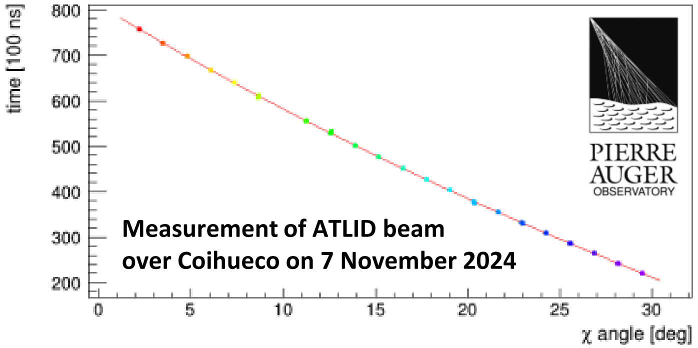
First detections of ATLID beam at observatories

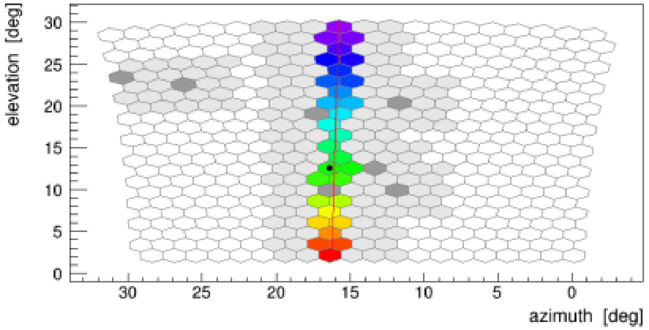
preliminary data

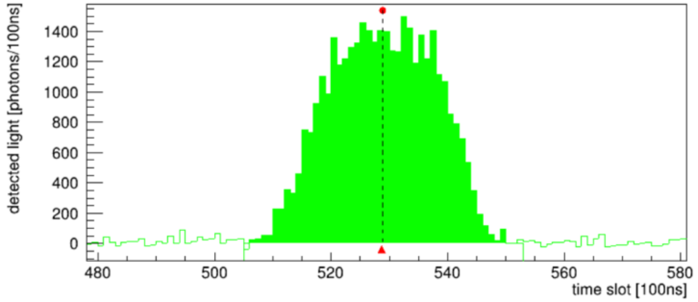
Detections on 29 October 2024, 7 November 2024



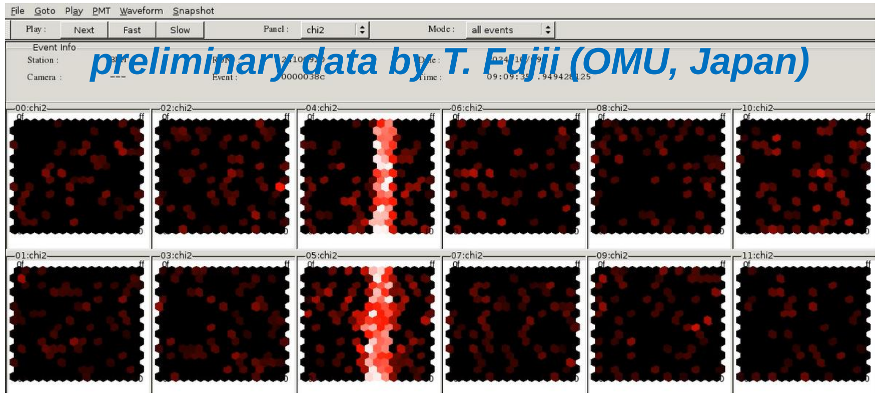




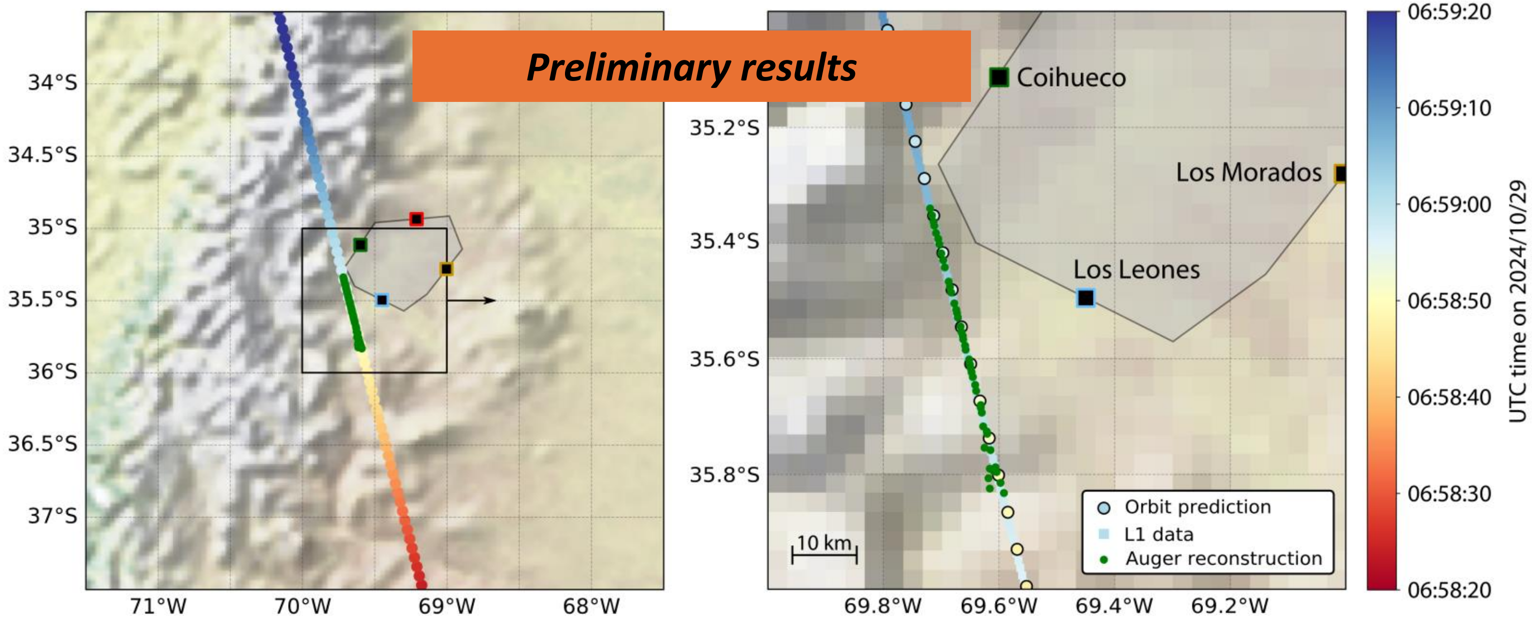




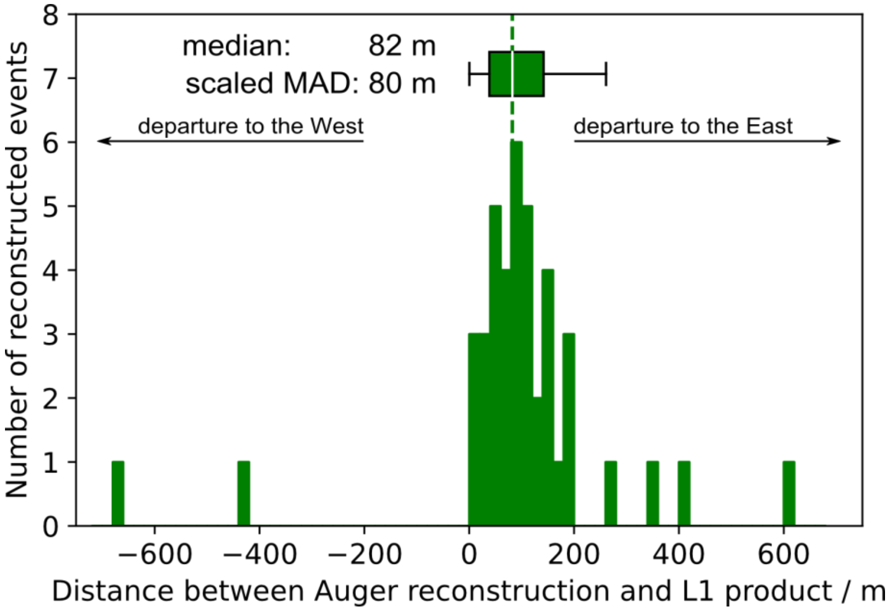
First detection at TA
(12 telescopes at Black Rock Mesa)
on 9 October 2024



Preliminary comparison of geolocation



- **EarthCARE overpasses Pierre Auger Observatory twice during its 25-day repeat cycle.**
- A western overpass occurred on 29/10/2024 around 6:59 UTC.
- The measurement conditions were excellent (cloud-free).

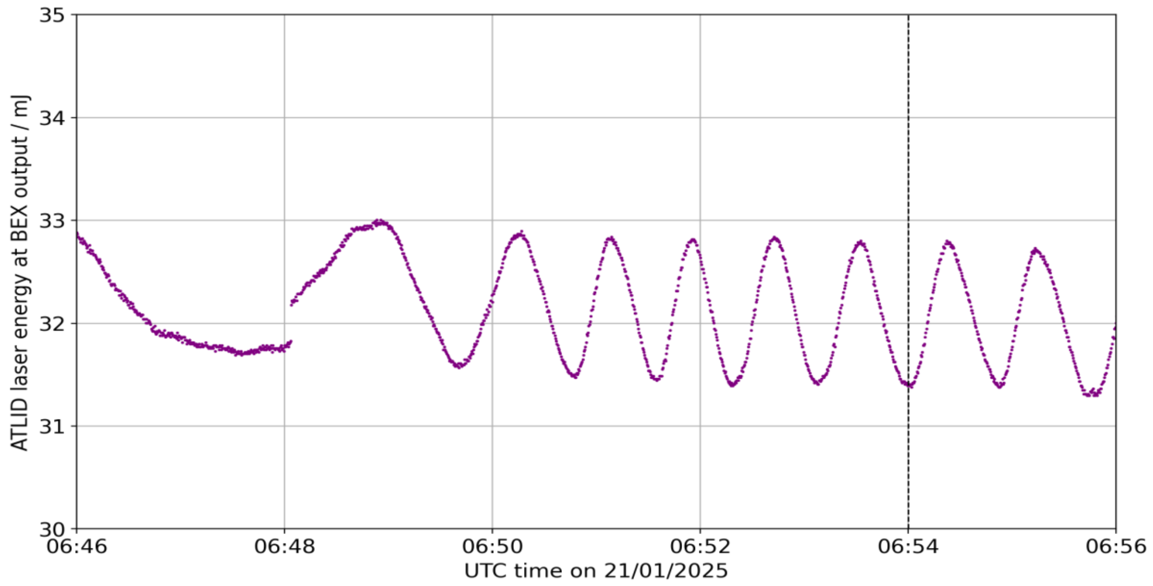


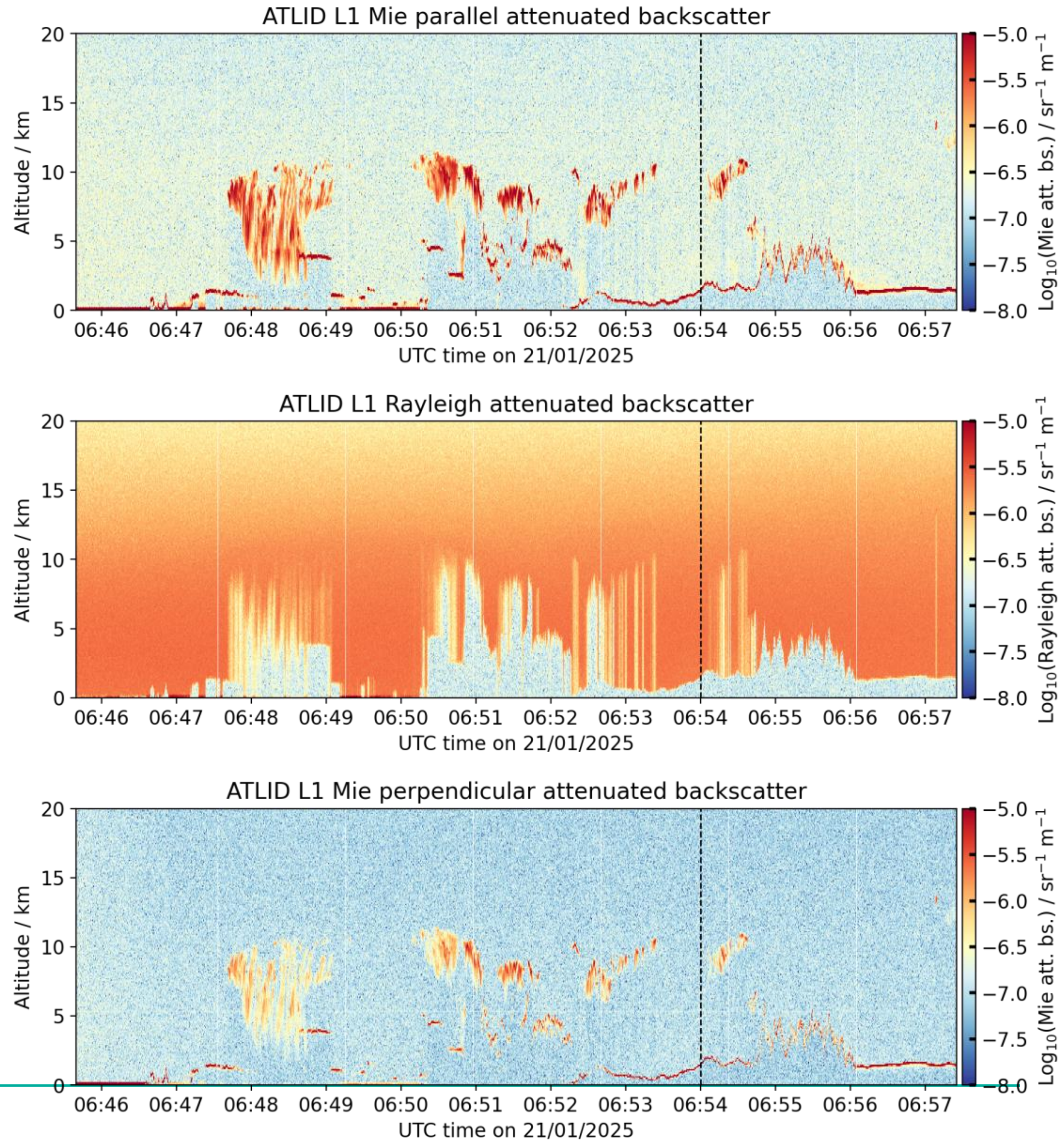
- Comparison of **ground tracks from geolocation data in the orbit prediction file** and those reported in the **ATLID L1B product show very good agreement**.
- Laser beam ground track, reconstructed by Auger measurements **at Coihueco**, is well aligned with the ground track reported in the L1 product.
- Median departure is **lower than 100 meters**, but ***results are preliminary***.
- Further improvements will be possible by using stereo-reconstructions from 2 sites.

EarthCARE overpass on 21 Jan 2025 at Auger

- The **Mie and Rayleigh attenuated backscatter** provided in the ATILD L1B data points to favorable conditions during the overpass (low aerosol content, no clouds).
- The **laser energy at the output of the instrument** shows oscillations between 31.3 mJ and 33.0 mJ (5% p-p) with a varying period ranging from one to several minutes.
- Investigations by DLR pointed to a **time-shift in ATLID laser energy in the L1 product** (baseline AC) by 66 s compared to downlinked data in MUST, reported to ESA in February 2025.

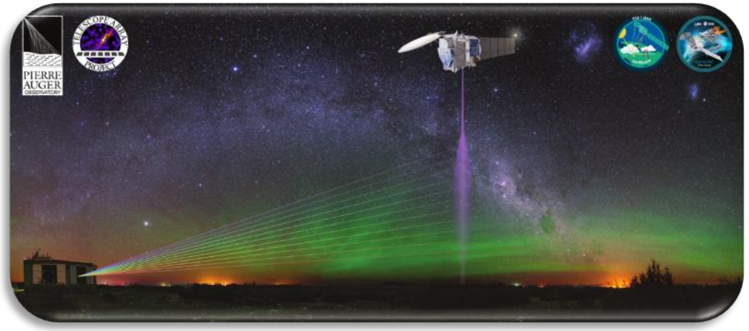
ATLID UV laser energy at the instrument output during overpass





Conclusion: Earth Observation meets Astrophysics

- **First, serendipitous discovery of a space-borne ultraviolet laser beam from Aeolus** by an Earth-based observatory designed to detect ultra-high-energy cosmic rays – the Pierre Auger Observatory, Argentina in 2019.
- These measurements allowed for a **precise geolocation of the Aeolus laser beam and absolute measurements of the laser energy within 10%;** observations were limited to May-August for the Aeolus dawn-dusk orbit during darkness at the observatory site.
- **EarthCARE ground-track** with 25 d repeat cycle and night-time ascending orbit **is favorable to be observed by the Pierre Auger and the Telescope Array** the whole year, but also for the Cherenkov telescope sites (VERITAS).
- The Pierre Auger observatory is a well-equipped ground-sites for **atmospheric monitoring including elastic and Raman lidars at UV wavelengths** → potential for ATLID validation.
- First observations of the ATLID laser beam at Auger and Telescope Array in Oct-Nov 2024 **with median departures of geolocation of 100 m** (best case, preliminary) → re-construction of laser beam and energy is on-going work.
- It will be exploited if **ATLID can be used as a "calibration star"** for inter-calibration of the energy of cosmic-ray observations*



*B. Keilhauer, Proc. ICRC 2023; V. Verzi, Proc. RICAP 2024