

CTAO SOUTH-LIDAR

Date : 03/10/25

Statut actuel : Réalisation

Porteur Scientifique : **G.Vasileiadis**

Porteur Technologique : **P.Brun/O.Gabella**

PUBLICATION TO COME

A Raman Lidar using gated mode photomultiplier readout for the CTAO South observatory site

George Vasileiadis^a, Patrick Brun^a, Omar Gabella^a and Stephane Rivoire^a

^aLUPM, Place E. Bataillon 34095 Montpellier, France

ARTICLE INFO

Keywords:
Raman Lidar
Astroparticle Physics
Gamma Ray astronomy
Atmospheric studies

ABSTRACT

The future Cerenkov Telescope Array experiment (CTA) will reach a sensitivity and energy resolution never obtained until now by any other high energy gamma ray experiment. It is well known that atmospheric conditions contribute particularly in this aspect. Raman lidars can help reduce the systematic uncertainties of the molecular and aerosol components of the atmosphere so these performances can be reached. The motivation and design of a raman lidar system is described. It provides both multiple elastic and Raman readout channels and custom made optics design. Readout electronics incorporates a gated photomultiplier function mode to avoid electronic pulse saturation due to very high gain signals reaching the telescope from very low altitudes. Preliminary analysis show the actual performance of the lidar in consistency with the desired design goals.

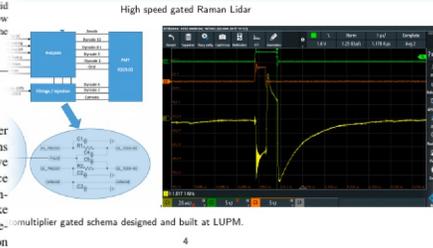
1. Introduction

The future Cerenkov Telescope Array experiment (CTA), will reach a sensitivity and energy resolution never obtained until now by any other high energy gamma ray experiment. It is well known that atmospheric conditions contribute particularly in this aspect. Current Imaging Atmospheric Cerenkov Telescope (IACT) experiments have pioneered several ways to introduce atmospheric calibration devices, among them the use of lidars. Their experience has led to a coherent atmospheric calibration strategy for the future CTA experiment. One of its key components consists of the assessment of the atmospheric extinction profile throughout the entire path that Cerenkov photons may take before getting imaged, at two wavelengths at least within the sensitive regime of the light sensors used in the CTA telescope cameras. To achieve this, one or several Raman lidars, operating at various wavelengths will provide extinction profiles, to continuously assess the atmospheric extinction across the observed science targets. Such an approach is sufficiently precise when either a single or no cloud layer are present in the observed field of view, a situation fulfilled practically all the time when CTA will be operative.

To precisely characterize extinction profiles up to 25-30 km height, the Raman lidar should use powerful laser and large reception mirror. These choices guarantees the highest precision at the expense of strong interference with the light sensors making it impossible to simultaneously operate both. Since the telescopes need to re-point frequently, the Raman lidar must therefore be able to measure the extinction profiles within short time scales typically a few minutes. Taking into account the size of used optics, back-scattered light from very low altitudes, few tenths of meters, became a big nuisance for the operation of the lidar, saturating both the photomultiplier and data acquisition operation chain. To overcome this issue, we have developed a high frequency gated photomultiplier base that permit us to mask the operation of the photomultiplier for these signals.

We report here on the design and performance of a prototype raman lidar conceived at the LUPM laboratory (Laboratoire Univers et Particules de Montpellier). Elastic and Raman spectra are presented with a preliminary analysis of the obtained profiles. These results confirms the conception design and solutions opted. The use of the gated photomultiplier high voltage base system demonstrates the benefits of such a development. We will refer to our system as LRL (LUPM Raman Lidar).

^aCTA sponsored
Corresponding author
george.vasileiadis@lupm.in2p3.fr (G. Vasileiadis)
ORCID(s):



Photomultiplier gated schema designed and built at LUPM.

of this pulse correspond to the OFF state and it is user adjustable. Normally it corresponds to the 300ms in altitude. After this time interval the photomultiplier regain its normal operational status. Figure 3b show the sampling pulse and the photomultiplier tube output. We used normal observation to obtain these data. The gain turnoff pulse was adjusted to an equivalent of 300ms for these tests, thus to observe at very low altitude with no interference from stray light coming from the laser. No observed during these tests, still more field testing is necessary to evaluate the full potential of this photomultiplier output signals are then fed to a standard industrial LICEL acquisition crate. It is equipped with 16 bits modules, while additional boards assure the synchronization of the laser trigger and DAQ, and data transmission to the main CTA-ACADA acquisition chain, is based on a UPC/UA driver

Results and performance studies

Months the LRL has been installed and operated at the Observatoire de Haute Provence (OHP), a typical site, where a number of optical telescopes are also installed and operational. The observation is pretty optimal to evaluate the performance of our lidar system. The vertical profile of the particle backscatter coefficient at 355 nm and 532 nm relies on the technique, and this is implemented following reception of the nitrogen vibration Raman signals at 387 nm, as proposed by Ansmann et al. The LIDAR equation for the elastic scattering signal is expressed

$$K_{s,R} \frac{O(z)}{z^2} [\beta_{aer}(\lambda_L, z) + \beta_{mol}(\lambda_L, z)] \times \exp\left[-\int_0^z [a_{aer}(\lambda_L, z') + a_{mol}(\lambda_L, z')] dz'\right] \quad (1)$$

$$P(\lambda_R, z) = K_{s,R} \frac{O(z)}{z^2} N_R(z) \frac{d\sigma_{\lambda_R}(\pi)}{d\Omega} \times \exp\left[-\int_0^z [a_{aer}(\lambda_L, z') + a_{mol}(\lambda_L, z') + a_{aer}(\lambda_R, z') + a_{mol}(\lambda_R, z')] dz'\right] \quad (2)$$

where $P(\lambda_R, z)$ are the return signals from distance z at the Raman wavelength of λ_R . $O(z)$ is the overlap correction factor. $N_R(z)$ is the molecule number density of the Raman-active gas and $d\sigma_{\lambda_R}/d\Omega$ is the Raman independent differential Raman cross section for the backward direction.

The particle extinction coefficient can be determined as:

$$a_{aer}(\lambda_L, z) = \frac{z}{K_{s,R}} \left[\frac{P(\lambda_R, z)}{P(\lambda_L, z)} - a_{mol}(\lambda_L, z) - a_{mol}(\lambda_R, z) \right] \quad (3)$$

Figure 4: Range corrected return signals (night-time) acquired during various data taking periods at OHP Observatory.

to calculate the backscatter coefficient. The elastic lidar equation first is normalized with its value at a specific reference height z_0 . Then the Raman lidar equation is normalized with its value at the same reference height. Finally normalized elastic and Raman equations are divided as illustrated in the equation below.

$$\beta_{aer}(\lambda_L, z) = -\beta_{mol}(\lambda_L, z) + \beta_{mol}(\lambda_L, z) \frac{\frac{z}{z_0} \left[\frac{P(\lambda_R, z)}{P(\lambda_L, z)} - a_{mol}(\lambda_L, z) - a_{mol}(\lambda_R, z) \right]}{1 + \left(\frac{z}{z_0}\right)^2} \quad (4)$$

To evaluate this equation, the reference height, z_0 , needs to be set. The reference height is normally set such that the backscatter coefficient from aerosols is much smaller than the backscatter coefficient from molecules. Then they (R)

Following approximation can be used $(\beta_{aer}(\lambda_0, z_0) + \beta_{mol}(\lambda_0, z_0)) \approx \beta_{mol}(\lambda_0, z_0)$ and the backscatter coefficient from molecules

The advantage with this procedure is that it makes the power of the laser, the height independent parameters and the overlap function to cancel out. It is assumed that the overlap function is the same for the Raman and elastic channels.

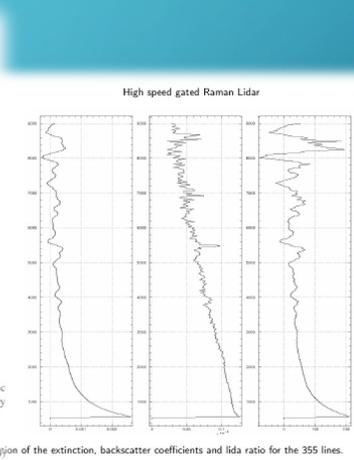
Finally the aerosol lidar ratio can be calculated :

$$LR_{aer}(\lambda_L, z) = \frac{a_{aer}(\lambda_L, z)}{\beta_{aer}(\lambda_L, z)} \quad (5)$$

The advantage of the Raman LIDAR technique is that it can measure extinction and backscatter directly, eliminating the need for an assumption of the extinction-to-backscatter ratios when solving the LIDAR equation. However, the only disadvantage of using the Raman LIDAR technique is the relatively weak Raman scattering compared to the Rayleigh or fluorescence scattering, but this limitation can be overcome by the use of high power lasers and/or long integration times. Thus aerosol optical property profiles can be resolved in both time and space, enabling a vertical snapshot for the precise identification of aerosol distribution.

We start by producing the range corrected signals for all elastic and Raman channels. The profiles are shown in Figure 4. We clearly distinguish the benefit of the photomultiplier gating mechanics described beforehand. The profiles are free of saturation, for altitudes as low as 300m. A value predefined in our data acquisition.

We continue by calculating the aerosol extinction and backscatter coefficients both for the 355nm and 532nm lines based on the formulation presented above. Typical results obtained are shown in Fig.5. for the 355nm line and Fig. 6 for the 532nm one. The presented profiles are extended for up to 10km in altitude. Results were similar for different nights taken during the same period. Still we are optimistic as of our design, since no real optimization was performed as of the gain of the PC and photon counting signals.



(a) of the extinction, backscatter coefficients and lidar ratio for the 355 lines.

2025

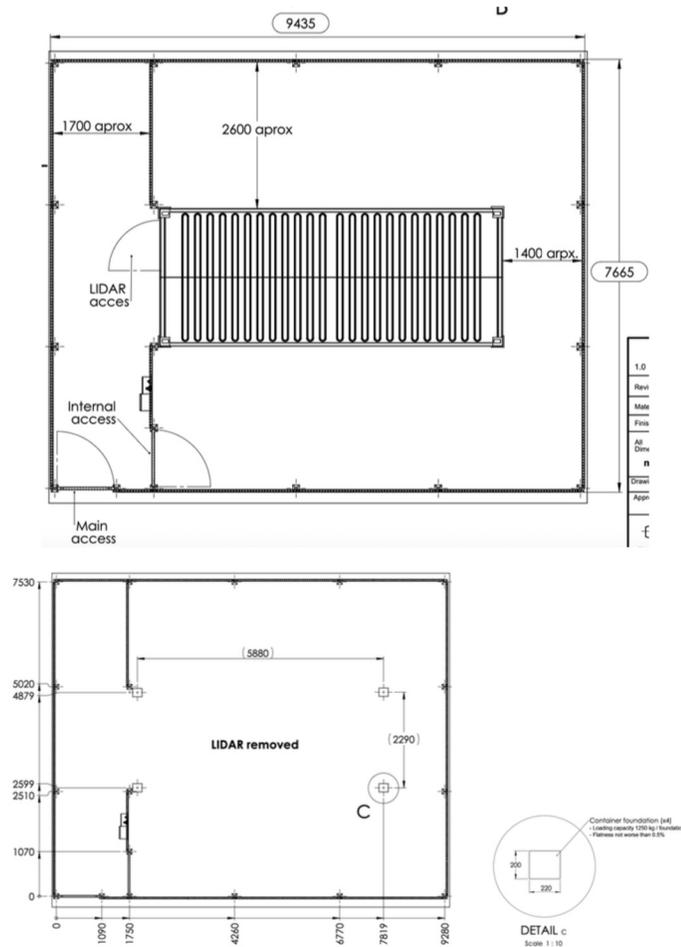
- 28k€ (LUPM)
- 6k€ (CTA-TGIR)
- Transport OHP-Montpellier / Chapiteau
- Missions OHP

@CTAO PREPARATIONS

CTAO

INTERFACE CONTROL DOCUMENT
CTAO-S SITE INFRA TO ACE

2025-09-19



Drawing of the fences around the RLDS **TBC by Team!!!**

CTAO South site
foundation
preparations

PERSONNEL

P.Brun

- End 2026
- NSIP : 20%
- Current : 2-3 days/week

G.Vasileiadis

- 5/5/2029
- Normally available...

O.Gabella

- NSIP : 40-50 % ?

S.Rivoire

- ?

LIDAR SCHEDULE

Installation on site

- Chile ..2027/2028
- Transport protocol 3-4m
- 3-4m commissioning

CDMR

- Documentations (a lot)
- FMEA/ Hazard analysis
- Seismic studies (*LLR/IJCLab*)
- Air traffic protocols (CTAO)

Montpellier on site

- Upgrade the Automation System
- Auto Alignment Optimization
- Measure individual Optical components (*L2C*)
- Production Electronics spares and tests (PMTs gating)
- Comply to CTAO security regulations
- Re-verify all operations

| Title | Doc. Number | Type | Panel Members |
|---|------------------------------------|-----------|-----------------------------|
| Level-B Requirements for the Raman LIDAR | | Reference | |
| Raman LIDAR Project Management Plan | | Review | All |
| Raman LIDARs Technical Design | | Review | All |
| Raman LIDARs Optical Design | | Review | All |
| Raman LIDARs PBS | | Review | All |
| Raman LIDARs Block Diagram | | Review | All |
| Raman LIDARs Technical Drawings | | Review | All |
| Raman LIDARs Tendering Specifications for relevant subsystems | | Review | All |
| Raman LIDARs Verification Plan | | Review | All |
| Raman LIDARs QA Plan | | Review | All |
| Raman LIDARs Hazard Analysis | | Review | Karl Tegel |
| Raman LIDARs Risk Register | | Review | Karl Tegel |
| Raman LIDARs Safety Plan | | Review | Karl Tegel |
| Raman LIDARs lightning protection plan | | Review | Karl Tegel Uwe Steinborn |
| Raman LIDAR -CTAO-S Seismic Protection Plan | | Review | Karl Tegel |
| Raman LIDARs FMEA | | Review | George Pruteanu |
| Raman LIDARs Maintenance Plan | | Review | George Pruteanu |
| LIDAR-Manager software design | | Review | Igor Oya |
| CTA Project Management Plan | CTA-PLA-MGT-000000-0003, V1c, 2020 | Reference | |

| | | | |
|---|------------------------------|-----------|-----------------------------------|
| CTA Construction Project Quality Plan | MAN-QA_110405 | Reference | |
| CTAO Documentation Control Plan | CTA-PLA-MGT-000000-0009 | Reference | |
| Calibration Concept for the CTAO | CTA-DER-ACS-00000-0001, v2.0 | Reference | |
| ICD Between ACADA – Raman LIDAR | CTA-ICD-SEI-000000-0038-1a | Review | Igor Oya Andrea Cremonini |
| Power Distribution System South (PDSS) to Array Common Elements (ACE) Generic ICD | CTA-ICD-SEI-000000-0021 1a | Review | Uwe Steinborn Andrea Cremonini |
| Layouts of the CTAO Arrays | CTA-SPE-PSC-000000-0001 2a | Reference | |
| CTAO – South Seismic Risk Specification | CTA-SPE-SEI-400000-0001-1c | Reference | |
| Telescope Grounding – Lightning and LEMP Protection | CTA-SPE-TEL-000000-0002-1c | Review | Uwe Steinborn Karl Tegel |

CDR Document List to provide

(partially in common with the Spanish Lidar)