32nd International Cosmic Ray Conference, Beijing 2011

Development of Raman LIDARs made with former CLUE telescopes for CTA

M. Barceló[1], O. Blanch[1], J. Boix[1], M. Bourgeat[2], M. Compin[2], M. Doro[3], M. Eizmendi[3], L. Font[3], D. Garrido[3], D. Glass[1], F. Grañena[1], A. López Oramas[1], M. Martinez[1], A. Moralejo[1], S. Rivoire[2], S. Royer[2] C. Sanchez[1], P. Valvin[4], G. Vasileiadis[2] for the CTA consortium
[1]*Institut de Fisica d'Altes Energies (IFAE), Barcelona, Spain*
[2]*Laboratoire Univers et Particules de Montpellier (LUPM), Montpellier, France*
[3]*Universitat Autónoma Barcelona (UAB), Barcelona, Spain*
[4]*Laboratoire Charles Coulomb (L2C), Montpellier, France*
alopez@ifae.es

DOI: 10.7529/ICRC2011/V09/0408

Abstract: The Cherenkov Telescope Array (CTA) is the next generation high-energy gamma-ray observatory. A proper characterization of the atmosphere will be crucial for reducing systematic errors in any data collected and allowing an increase in effective observation time. In an elastic backscattering LIDAR, the systematic error in the derived extinction can be as large as 20%, whereas in a Raman LIDAR it can be constrained to 3-5%. The Barcelona IFAE-UAB and Montpellier LUPM groups are each building a Raman LIDAR based on former CLUE telescopes optimized for the future CTA observatory. In this work we present the basic design, adopted solutions and expected performance of the LIDARs.

Keywords: IACT, CTA, Raman LIDAR, Calibration

1 Introduction

Ground-based Cherenkov telescopes of the Imaging Atmospheric Cherenkov Telescope (IACT) class observe cosmic gamma rays in the GeV–TeV regime by collecting the Cherenkov light produced by electrons and positrons in electromagnetic showers initiated by primary gamma rays when interacting in the top Earth atmosphere.

The current generation of IACTs, and specially HESS[1], MAGIC[2] and VERITAS[3] have most of their systematic errors in the energy reconstruction and absolute scale of the gamma-ray measured fluxes due to systematics in the determination of atmospheric parameters. Of particular concern is the poorly known total extinction that Cherenkov photons undergo in their travel from the emission region, typically located between 20 and 10 km a.s.l., to the ground. The atmosphere in fact acts as a calorimeter for the development of the atmospheric showers, and therefore its characteristics (both the molecular and particle content and profile) affect the transmission of photons and eventually the reconstruction of the primary gamma-ray energy.

To date, moderate effort has been expended in characterizing and monitoring the atmosphere above the telescope and, in general, data are not corrected for the actual atmospheric conditions, but rather discarded when the atmosphere gets too opaque, as in the case of the presence of dense clouds. On the other hand, IACTs can operate in moderate hazy atmosphere, when the extinction of the Cherenkov photons is not significant. In such conditions, the only thing that must be done is to check the effect on the data, e.g. the diminution of the effective area, the reduced efficiency, the possible variation in the shower intrinsic parameters, etc. and hopefully correct the data with this information. This can be done through Monte Carlo simulations and is currently under investigation in several groups of the Cherenkov Telescope Array (CTA) consortium.

Following another approach, the characterization of the atmosphere at night can be done through the use of Light Detection and Ranging (LIDAR) systems [1], which is the subject of this proceeding. A LIDAR is composed of a laser pointing at the atmosphere, a curved mirror which collects the light of the laser scattered back by atmospheric molecules and particles, and focusses it on a photon detection device. By accurate time measurements, considering the two-way path of the light in the atmosphere (upward and downward), one can also derive the altitude of the interaction region between the laser beam and the atmospheric constituents.

In a simplified approach, the laser photons can undergo two types of scattering (elastic and inelastic) and interact with two families of atmospheric constituents: the *molecules* (like N_2, O_2, H_2O, CO_2, etc.) and the *parti-*

---

1. www.mpi-hd.mpg.de/hfm/HESS/
2. www.magic.mppmu.mpg. de
3. veritas.sao.arizona.edu/

cles or *aerosols*, mainly constituted by minerals, pollutants, sand, etc. The aerosols are characterized by bigger size than molecules, reaching up to several μm. Scatterings with molecules are called Rayleigh scattering and modeled with the well-known Rayleigh formula for the cross-section: $\sigma(\lambda) \sim \lambda^{-4}$. When the particle size is of the order of the impinging wavelength, as is the case of aerosols, the Rayleigh formula does not hold, and the more complex Mie interaction theory is used. In such situations, the cross-section scales with the Ångström coefficient, which typically goes from 0.5 to 1.5 depending on the aerosol type.

In the following, we will restrict ourselves to the description of a *Raman LIDAR*, which is a LIDAR that not only measures the elastic scattering, but also the rotation and vibrational inelastic scattering (which occurs basically only with the molecular component). Despite the fact that inelastic scatterings are two-three orders of magnitude less frequent than elastics ones, they are extremely useful because they allow to disentangle between the Rayleigh and Mie scattering, which is normally a large source of uncertainty in the estimation of atmospheric extinction from purely elastic LIDAR.

The development of these Raman LIDARs are conducted in the context of the ATAC working group of the CTA consortium. CTA is currently merging the worldwide effort for Cherenkov telescopes towards a new huge installation of several tens of dishes of several sizes to operate simultaneously[4] [4]. This will guarantee a boost in the performance compared to actual installation. The project is in the preparatory phase and will be completed around 2015–2020. The Raman LIDARs will be installed and operated at the CTA site, with the goal of reducing the systematic uncertainties of the imaging atmospheric Cherenkov technique of the telescopes and increasing the duty cycle thanks to a better knowledge of the atmosphere.

2 Overall Design

In the following we will describe the joint effort of three institutes: IFAE-UAB (Barcelona, Spain) and LUPM (Montpellier, France) for the construction of Raman LIDARs through the recycling of a CLUE telescope hosted in a foldable container. A visual picture of the container and the telescope is shown in Fig. 1.

2.1 The CLUE container and telescope

Three CLUE containers and telescopes were bought to be reassessed as LIDARs, two by IFAE and one by LUPM. They are standard 20-foot shipping containers, with the top and side walls modified as two shells that can be opened to let the telescope inside move. The telescope is composed of a parabolic solid-glass mirror, of 1.8 m diameter, produced at CERN [2, 3]. The focal plane is also at 1.8 m from the mirror (thus the f/D ratio is 1) and was hosting a small (20×20 cm) MWPC (Multi Wire Proportional Chamber) that was removed. The container hosts two motors to open the shells and the telescope has one azimuthal and one zenithal motor for positioning, that can be remotely operated. The telescope has additional four motors to open four petals that protect the mirror.

Figure 1: Picture of the CLUE telescope and the foldable container when it was operating in La Palma (Spain). The telescope will be re-designed as Raman LIDAR.

The primary mirror, produced in 1998, has maintained a good geometry, with 80% of the light contained in a circle of 6 mm diameter, almost as when produced. On the other hand, its reflectivity has dropped significantly, due to a missing protective coating. We are currently understanding whether refurbishment is feasible if not we could produce spare mirrors.

2.2 The LASER and its optics

IFAE-UAB and LUPM equipped the LIDARs with Nd:YAG lasers, that can provide simultaneously three wavelengths (1064 nm and its first two harmonics 532 and 355 nm). IFAE-UAB laser is a `Brilliant`^{TM} compact Q-Switched laser, with a beam diameter of 6 mm and divergence of 0.5 μrad, with harmonic generator module including separation package in order to select the channels. At 355 nm, where our interests are concentrated[5], we can select 10, 20, 50 Hz as pulse repetition frequency, with 100, 70, 20 mJ energy per pulse respectively, with a pulse duration of ~4 ns. LUPM will use a CFR-400 Q-Switched laser, with a beam divergence of less than 1.2 mrad and a beam diameter of 7 mm. The pulse repetition rate is fixed 20 Hz, while the beam energy is 400, 230 and 90 mJ for the first, second and third harmonic respectively with a pulse duration of ~7 ns.

---

[4] http://www.cta-observatory.org/

[5] The Cherenkov emission ranges from UV to visible, and is peaked at around 290 nm.

The laser is mounted at one edge of the mirror, at around 0.9 m from the optical axis. The bi-axial design in general does not allow a good sampling of the atmosphere in the proximity of the LIDAR (near range), because there is only a partial ”overlap” between the backscattered light reflected onto the focal plane and the photon sensitive area. To maximize the overlap, the laser beam is guided to the optical axis through the use of two 45 deg high reflective mirrors mounted on special adjustable supports. IFAE-UAB bought two `MI1050-SBB` 1’ fused-silica mirrors from `Precision Photonics`^{TM} with surface figure of $\lambda/10$, damage threshold of >1 J cm^{-2} at 355 nm and reflectivity above 99 %.

A high precision alignment between the laser and the optical axis is needed to be able to get information from the farthest distances. For the IFAE-UAB case a micrometer stepping motor moving the laser head ensures the requested precision.

2.3 Focal plane and light transmission

The scattered light that is collected by the primary mirror is focussed onto the focal plane. The parabolic shape ensures that light coming from infinity is focussed with the minimum point spread function (PSF), while light coming from the near range is focussed on a broader circle (but still centered in the optical axis in case of a mono-axial system). Given that 80 % of the light is focussed within 6 mm diameter, IFAE-UAB has chosen to transport the light with an optical fiber fixed at the center of the focal plane to the rear of the telescope where the optical bench and acquistion system are placed. The guide is a liquid optical guide from `Lumatec`^{TM} of 8 mm diameter and 3.2 m length, guarantees an almost flat transmission of 75 % in the range from 300 to 650 nm (intense light with frequency above 650 nm would damage the guide) and can operate between -5 and 35°C. LUPM uses a *ThorLabs*^{TM} 8 mm liquid fiber with a total length of 4 m. Transmission is better than 70 % from 400 to 750 nm.

IFAE-UAB tested the light guide, and confirmed the producer specifications. In general, the light guide transmission does not depend on the way the light guide is enrolled, does not change within temperature between 0 and 30°C, and does not depend significantly from the incident angle below 30 deg (given the mirror diameter and the focal distance, the maximum incident angle is 27 deg). At the exit, the light beam keeps the incident angle, although the direction is randomized forming a circumference from a single incident point.

For the IFAE-UAB LIDAR, the light guide needs to be protected with a low-pass optical filter placed at the focal plane before the entrance to cut above 650 nm. In addition, possibly a collimating lens will be placed at the entrance of the fiber to reduce beam divergence.

2.4 Optical bench

The optical bench will be placed at the exit of the optical fiber. It will be composed of a collimating system (still to be defined) and by a series of dychroic mirrors, filters and reflective mirrors, that are needed to select specific wavelengths of interest. There is still an important debate about how many and which are the wavelengths that one should measure to well determine the atmosphere for the purpose of IACTs. Typical ones are the elastic channels at 1064, 532, 355 nm and the Raman channels of the N_2 of the first and second harmonics at 607, 387 nm. On the other hand, different solutions can be applied that can use O_2 Raman channels, water vapor channels, CO_2 channels, the transverse and parallel polarization of the elastic channels, etc. The baseline design foresees the use of 355 (elastic) and 387 nm (N_2 Raman) for IFAE-UAB LIDAR and the additional 532 (elastic) for LUPM. On the other hand, in the case of IFAE-UAB LIDAR, the optical bench has been designed to have enough modularity to easily add or remove channels.

Once the wavelength is selected, the beam is focussed onto an hemispherical photomultiplier tube (PMT). We received offers from `Hamamatsu`^{TM} for two PMTs, `R1924A` and `R329P` of 25 and 51 mm cathode diameter respectively. The choice of the PMT will be done after the optical bench will be simulated to understand at which level the light beam can be collimated and transported. The PMTs are optimized for LIDAR purposed, with background noise at 3 nA, gain at $\sim 10^6$, single photo-electron capability, and in general with good environmental ruggedness to be used in outside installations.

2.5 Readout

In general, each channel must read return power that spans more than six order of magnitude, from the mW received from the near range in the elastic case, to the nW received from 10-15 km in the Raman case. Typically, this problem is approached by using a duplex readout that provides both an analogue readout for the near range and a photon counting readout for the far range, with an overlap region at moderate altitudes (around 5 km).

Commercial modules are available and both groups contemplate to equip the LIDAR as a default option with standard `LICEL` modules. In parallel, the IFAE engineer team is developing a customized alternative with emphasis on getting the maximum information for the highest distances.

2.6 System control

The system control still must be developed. It can be divided in two sectors. The front-end part controls the LIDAR hardware: container motors, the telescope petals, the telescope pointing, the trigger of the laser, etc. The integration part exchanges information with the central control system of the CTA observatory. While the former system will be probably controlled by `c++` code programs, the latter one will be written in the standard CTA control software `ACLI`.

3 Outlook and conclusions

In this proceedings, we have presented the effort for the reassessment of three decommissioned CLUE telescopes to be used as Raman LIDARs for the atmospheric monitoring and characterization for the future CTA observatory. The goal is to increase the duty time by observing during moderate hazy atmosphere conditions and to reduce the systematic errors on the energy distribution through a deeper knowledge of the effect of atmospheric properties on the data.

Two institutes in Barcelona (Spain), IFAE and UAB, and LUPM in Montpellier (France) are currently collaborating for the construction of the LIDARs, despite different solutions are currently adopted. A fourth insitute, CEILAP in Buenos Aires (Argentina) is also developing a different design of Raman LIDAR, presented elsewhere in this conference.

Our primary goal is to have the complete design fixed by the end of the year, specially for the optical bench, and finish the construction by summer 2012. After a characterization campaign in Barcelona and Montpellier, the LIDAR may be shipped at the (yet non defined) CTA sites.

We gratefully acknowledge financial support from the agencies and organisations listed in this page: http://www.cta-observatory.org/?q=node/22

References

[1] Weitkamp, C. editor, 2005, LIDAR Range-Resolved Optical Remote Sensing of the Atmosphere, Weitkamp, C., Springer
[2] Baillon et al., NIM A, 1989, **276**: 492-495
[3] Baillon et. al., NIM A, 1989, **277**
[4] CTA Consortium Collaboration, Hoffman, W. and Martinez, M., Design Concepts for the Cherenkov Telescope Array, ArXiv e-prints (2010) [astro-ph.IM/1008.3703].