CTA Raman LIDAR Pathfinder Technical and Scientific Description

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1 Introduction and Context

Remote-sensing instruments, like elastic or Raman LIDARs, have proven powerful tools to characterize the atmosphere, since the laser light emitted by the LIDAR directly interacts with the atmospheric constituents and provides in return the footprint of atmospheric ingredients at each altitude. A Raman LIDAR is therefore foreseen in the CTA baseline configuration, to determine atmospheric transmission from each point along its line-of-sight to ground, up to distances of 30 km. The Raman LIDAR constitutes a crucial element to provide the requested improvement in reducing systematic uncertainties and increasing the duty cycle for the CTA observatory, compared to the current generation of Cherenkov telescopes. It is an important part in the architecture of CTA, particularly for atmospheric calibration [1-4].

[1] Actis, M. and others (2011). Design concepts for the Cherenkov Telescope Array CTA: an advanced facility for ground-based high-energy gamma-ray astronomy, Experimental Astronomy, 32, 193-316.
[1] Chadwick, P., Förster, A., Gaug, M., Hörandel, J., and others (2014). Common Technology Evaluation, Testing and Calibration Technical Design Report (CTA Internal Report COM-TDR/140721).
[2] Gaug, M. (2017). CTA Atmospheric Calibration, EPJ 144, 01003.
[3] Gaug, M. (2019). Calibration Concept for CTA-North (CTAO Technical Report COM-CCF/190211).

2 Basic Principles

L.I.D.A.R. (Light Detection And Ranging) is an optical remote sensing technique analogous to the RADAR principle. It is based on a laser which emits light pulses toward the atmosphere, a telescope which collects the backscattered light, a polychromator unit where the light is distributed to the sensors and an acquisition unit. Since light travels at a known speed, the atmosphere can be characterized in range from the time delay between the pulse emission and its reception. When the laser beam interacts with the atmospheric components (aerosols and molecules), the light is scattered basically in all directions (e.g. through Mie and Rayleigh scattering). A fraction of this light is scattered back to the telescope and collected. The amount of light collected carries hence information about the amount and type of the scattering particles at the sensed distance and the amount of extinction suffered after travelling back and forth to the scatterers. **Figure 1** provides a simplified scheme of the main components of a LIDAR.

The Raman LIDAR technique, in turn, makes use of the weak inelastic scattering of light by atmospheric molecules, where different rotational and vibrational molecular energy levels are excited. Raman LIDARs usually detect the wavelength change from the first to the second vibrational quantum state of N_2. Because Raman scattering cross sections are several orders of magnitude smaller than elastic ones, large mirrors and strong lasers are needed to achieve significant detection of the Raman back-scattered light.

Modern Raman LIDAR analysis techniques achieve systematic uncertainties of (10-20)% for the extinction coefficient [1,2], which translates into (5-10)% for the integrated transmission, measured at the operation limits of CTA, related to atmospheric obscuration. The use of more than one laser wavelength, an absolute calibration of the LIDAR, and particularly cross-calibration with other instruments and methods can further improve these numbers.

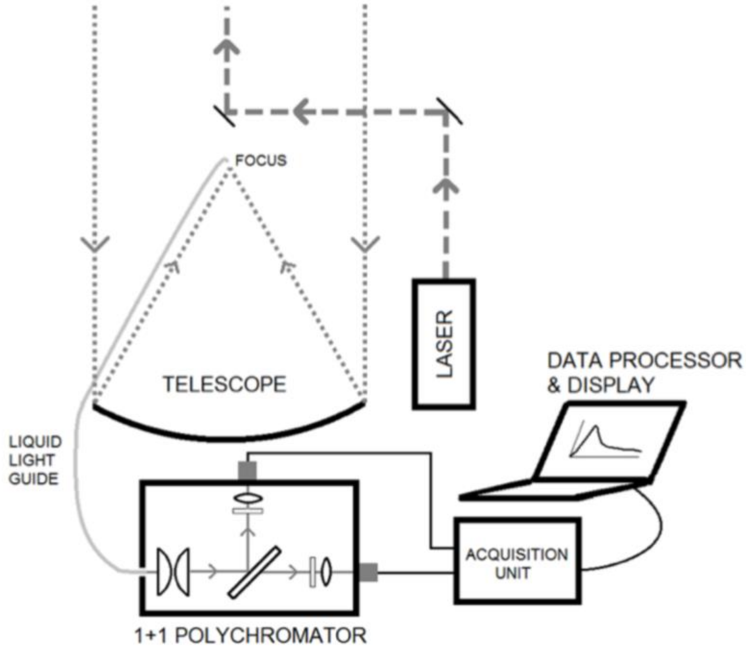


Figure 1: Simplified scheme of a Raman lidar for CTA. The light beam from a laser is guided toward the atmosphere in a coaxial configuration with a telescope that collects the backscattered light. At the focal plane, a light guide transports the light to a polychromator unit which is controlled and readout by an acquisition system and a data processor unit.

[1] Ansmann, A. et al. (1992). Independent Measurement of extinction and backscatter profiles in cirrus clouds by using a combined Raman elastic-backscatter lidar, Appl. Opt., 31, 7113
[2] Pappalardo, G. et al. (2004). Aerosol lidar intercomparison in the framework of the EARLINET project. 3. Raman lidar algorithm for aerosol extinction, backscatter, and lidar ratio, Appl. Opt., 43 (28), 5370-5385

3 CTA Requirements for a Raman LIDAR

It was soon realized [1,2] that CTA needs a highly specialized version of a Raman LIDAR, fulfilling the following requirements:

1. The aerosol transmission profile along the line-of-sight of CTA must be monitored up to an altitude of 15 km a.s.l.
2. The profiling must be possible for any direction within the Observable Sky of CTA, i.e. up to a range of 30 km at least.
3. The transmission profile must have a range resolution of at least or better than 300 m.

4. The aerosol transmission must be measured with an absolute accuracy better than 0.05.
5. The wavelength dependency of aerosol transmission (Ångström exponent) must be monitored over the full altitude profile, for the wavelength range to which the CTA-N telescopes are sensitive.
6. Independent cross-checks for the measurement accuracy of the aerosol transmission profiles and maps must be made available to ensure a robust system.

In order to determine the full ground layer transmission reliably, the LIDAR should be equipped with additional near-range optics and/or a calibrated system constant. Moreover, stratospheric aerosol extinction should be accessible by the LIDAR, at least when pointing towards the zenith.

Since the CTA telescopes will be blinded by a LIDAR producing laser pulses propagating into their field-of-view, the LIDAR shall permit to characterize one profile a few minutes before and after a CTA Observation Block, and during a change of Wobble position. In the latter case, the LIDAR measurement shall be accomplished after only one minute of data taking.

Finally, the LIDAR shall fulfill all general and environmental requirements established for CTA and be designed for a lifetime greater than 15 years, requiring less than 2 person-hours/week routine preventive maintenance and less than person-hours/week for corrective maintenance.

[1] Doro, M. et al. (2014). Atmospheric Calibration for CTA (CTA Technical Report COM-CCF/130311).

[2] Doro, M. et al. (2014). Status and motivation of Raman LIDARs development for the CTA Observatory, Proceedings of the First AtmoHEAD Conference, Saclay.

4 Design Choices for the Barcelona Raman LIDAR

The Barcelona Raman LIDAR has been constructed according to the following design choices:

- Full access to the nearest and farthest ranges required. This has led to a **coaxial** beam configuration for the laser steering optics, in order to minimize the distance from ground to the range of full overlap (~150 m). Moreover, additional **near-range optics** has been implemented allowing characterizing the atmosphere starting with a distance of 20 m from ground.
- To access the farthest distances required, a **powerful laser** of 160 mJ output energy per pulse was selected, together with a **large parabolic mirror** of 1.8 m diameter. The Newtonian reflector with *f*-number 1 and a large pinhole of 8 mm allows for large depths of field.
- The mirrors are mounted on a telescope, which can **point to any azimuthal** direction and **zenith angles down to 75 deg**.

- The LIDAR operates simultaneously at the UV **wavelength of 355 nm** (right at the maximum sensitivity of the CTA telescopes) and a second green line of **532 nm** (where sensitivity of CTA telescopes has dropped to about one half), together with their corresponding N_2 **Raman** vibration Stokes **lines of 387 nm and 607 nm**.
- The LIDAR can access any point in the sky within a minute.

5 First Results

Analysis of the commissioning data taken at the (non-optimal) current location of the Barcelona Raman LIDAR at the Campus of the Universitat Autònoma de Barcelona is still ongoing. Nonetheless, first results indicate that the Barcelona Raman LIDAR is on the right way to fulfil the CTA requirements for a Raman LIDAR [1,2].

Figure 2 shows one of the first-light range-corrected signals for the two elastic and one Raman line, taken within less than one minute. It is clear that the LIDAR easily reaches 30 km distances, at least with the elastic UV line. Note that these figures represent, however, a lower limit to the achievable performance, because the primary mirror had become dirty and not yet been cleaned.

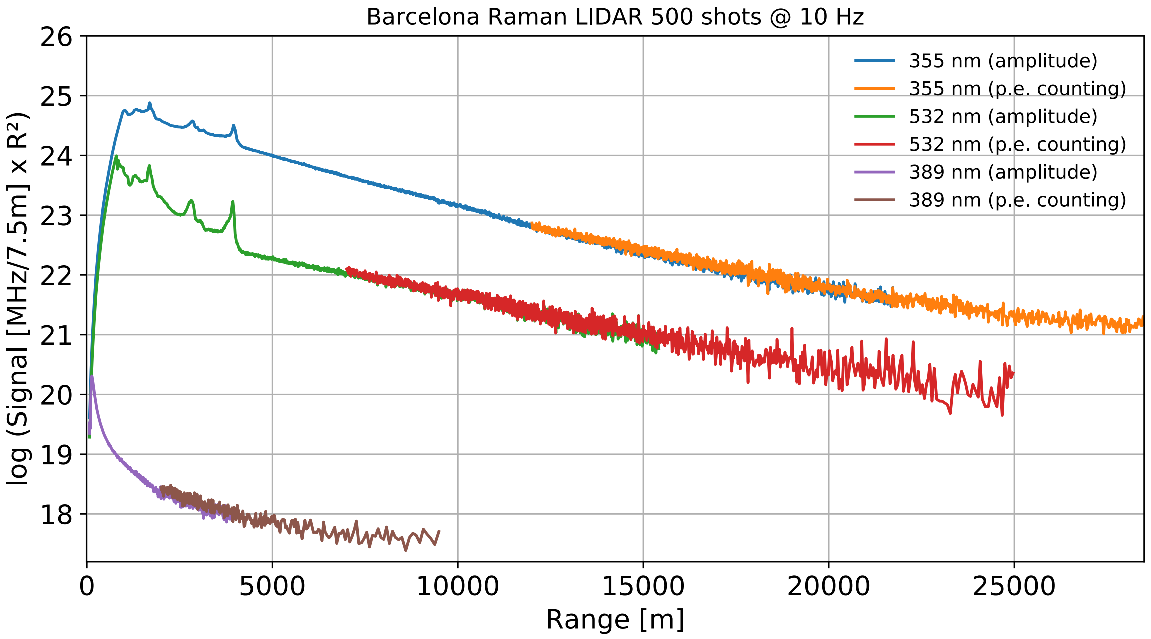


Figure 2: First light range-corrected signals from the three colour lines of the Barcelona Raman LIDAR (two elastic and one Raman channel), based on 50 s (500 laser shots) of oversampling. The analog (amplitude) and photo-electron (p.e.) counting parts are shown where applicable. The features visible in the elastic lines below 4 km correspond to aerosol layers and clouds.

[1] Gaug, M. et al. (2019). The IFAE/UAB Raman LIDAR for the CTA-North, EPJ Web of Conferences, 197, 02005.
[2] Ballester, O. et al. (2019). Raman LIDARs for the atmospheric calibration along the line-of-sight of CTA, Proc. 36th International Cosmic Ray Conference -ICRC2019- Madison, USA, PoS(ICRC2019)814.

6 Sub-Components of the LIDAR

6.1 The Container

The container is a 20 ft standard container with external dimensions of 6.06 × 2.44 × 2.59 m, customized to house all the Raman LIDAR instrumentation and protect it from the environmental conditions. Altogether the container and instrumentation weigh about 3 t. To operate the LIDAR, the container must be opened as shown in **Figure 3**.

Figure 3: Photograph of the container in open position

6.1.1 Motors and Actuators

Each container door is equipped with a *Servomech* linear actuator (ACME screw actuator – trapezoidal thread) powered by a 1.5 kW IEC standard motor (see **Figure 4**). To stop the opening/closing movement, each linear actuator is equipped with two end-switches. Because the opening/closing order is also important, there is another switch to ensure that this manoeuvre is carried out properly. The container doors cannot be opened/closed unless the telescope is in the parking position, and this position is defined by two more switches (installed in the telescope).

The switchgear cabinet, which controls the opening/closing movements, is installed beside the right linear actuator holding structure. The container doors can be opened/closed either remotely or manually by means of a joystick. This joystick is installed in the right linear actuator holding structure.

The container can be opened and closed completely within one minute.

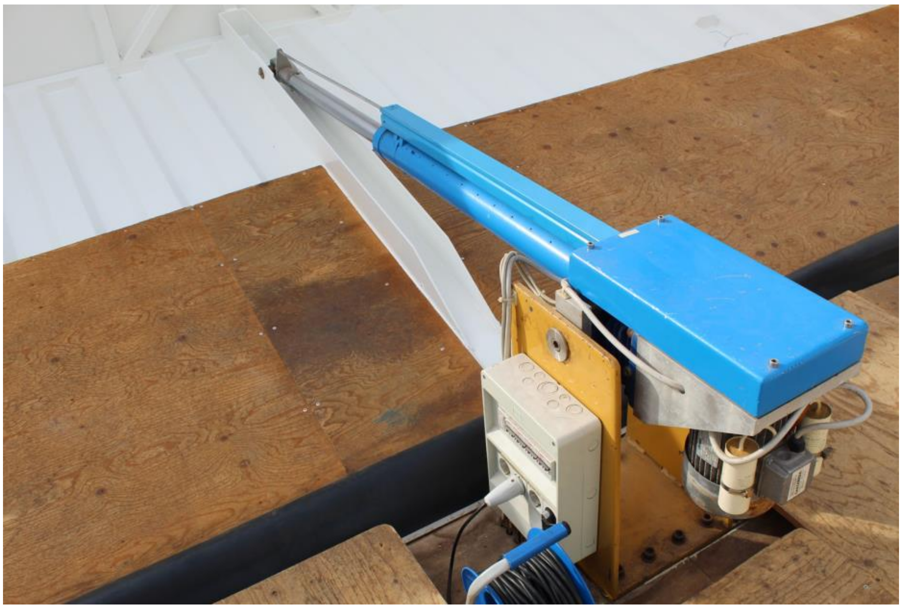


Figure 4: Photograph of one of the two actuators. The black band spanning from the lower left corner to the central right is the dust protection rubber seal.

6.1.2 Supplies

Apart from the Container itself, there are two cabinets, one emergency push-button and a key switch that are going to be installed outside the container.

The supplies required for the Raman LIDAR are:

- A single phase power line AC 230 V (± 5%) at 50 Hz (± 2%) to be connected at the larger cabinet.

- An Ethernet connection to be connected at the smaller cabinet.

6.1.3 Transport

Because the container is cut into halves, it must be properly fixed during transportation. Apart from fixing the container, the telescope is also fixed, and the laser is unmounted and located inside a cushioned wooden box tailored for this purpose.

All the transport tools have been designed to be kept inside the Container when they are not needed.

6.2 The Telescope

6.2.1 Chassis

The chassis was designed to support a 1.8 m mirror in an alt-azimuth mount, allowing for zenith and azimuth movements. The chassis also holds the petals and supports the optical system in the focal plane. **Figure 5** shows the entire telescope structure in parking position.

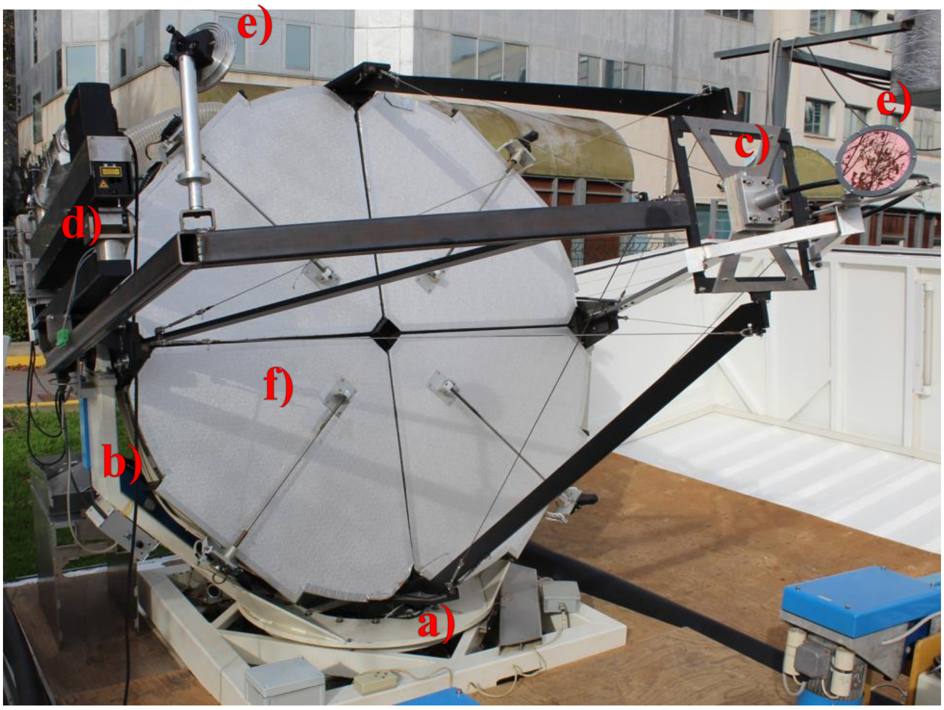


Figure 5: Parts of the chassis: the metal platform that support the azimuth movement (a), the U-form structure that supports the zenith movement (b), the focal plane support (c), the structure for the laser arm (d), the support for the small mirrors to align the laser beam (e) and the petals (f).

6.2.2 Primary Mirror

The LIDAR is equipped with a 1.8 m diameter parabolic mirror of *f*-number 1 (i.e., the focal length is also 1.8 m), produced for the *CLUE* (Cherenkov Light Ultraviolet Experiment) experiment in Padova [1], following a slumping technique invented at CERN (see also [2,3]). With respect to [2], some simplification and modifications have been adopted, dictated mainly by the larger size. The mould was cast in a special stainless-steel alloy *STAVAC ESR AISI* 420 with low thermal expansion coefficient ($13 \times 10^{-6}\,^{\circ}$C), close to that of the glass used ($8.5 \times 10^{-6}\,^{\circ}$C) with low carbon and high chromium (0.5% C, 13% Cr) content. It was machined to a concave parabolic shape with a digitally controlled lathe with a nominal accuracy of better then 20 μm. The mould of this mirror is currently located at the *Legnaro INFN laboratories* (Padova, Italy).

The mirror was made with float glass with a particularly smooth surface, specially produced by *Società Italiana Vetri of Porto Marghera* (Venice, Italy). The deviation of the mould from the nominal parabolic surface and the defects of the glass plate introduced differences on the slope of the parabolic mirror of less than 1.6 mrad, these effects enlarge the image in the focal plane by 5.8 mm at maximum. To produce the mirror, a disk of 6 mm thick float glass is placed on the mould, and both are introduced in a large electric oven at the firm *Sunglass of Villafranca Padovana* (Italy). The mould, having a mass of 1.5 t, is heated by three rings of electric heaters placed on its back and dissipating 40 kW. The heaters of the oven are used essentially to keep the air above the glass at the same temperature as that of the mould. When the temperature reaches 600°C the process of slumping starts. At this point, the glass is sufficiently soft to be slumped against the parabolic surface by sucking air with a vacuum pump. Upon cooling, the blank is obtained. The reflective coating is vacuum-evaporated with a layer of aluminum of 80 nm thickness, it was not quartz-coated. The coating process was made at *Osservatorio Astrofísico of the University of Padova*, Asiago (Italy).

The mirror spot size has been characterized through its PSF by different methods and experiments [4], pointing the telescope to *Polaris* and analyzing the focused spot at the focal plane, or using an artificial star target at 65 m distance. In both cases, the resulting images were taken with a *CANON EOS 1000D* mounted behind the focal plane and analyzed using the IRAF package, an extension of ROOT. After subtracting the background, the program searches for the spot maximum by scanning the image and calculates the center of gravity of the spot. Finally, different containment radii are calculated.

Both methods show that 80% of the light is contained in an area of ∼6 mm diameter, whereas 90% fall in a circle with a diameter of about 6.5-7 mm. Practically all light is enclosed inside a circular area of radius 8 mm.

The roughness of the mirror is 2–3 nm with an initial reflectivity of 95%. The peak- to-valley due to thickness and parallelism imperfections of the glass and the mould have been measured to 1.34 mrad. After 4 years of operation, the mirror was re-aluminated at La Palma at the Herschel observatory, because the reflectivity had degraded to 50-60%.

6.2.3 Motors and Endswitches

The movement of the telescope in both axes is carried out by *VEXTA* (now called *Oriental motor*) stepper motors, coupled to *Bonfiglioli* gearboxes that directly drive either the zenith/azimuth axis by means of a system made of pulleys, tensioners and a toothed timing belt.

The switches are used to ensure that limit positions are not exceed as well as to define the parking position.

6.2.4 Protection Petals

Added to the chassis are the petals, used to protect the mirror and, in addition, to cover the mirror avoiding sunlight reflection during daily operation and maintenance. The petals are made out of polystyrene. The four petals that cover the mirror are actuated by four 12 V motors and controlled by 8 end-switches connected in series (see **Figure 6**).

Figure 6: Photograph of one of the mirror protection petals.

6.2.5 Laser Arm

Figure 5 (d) shows the laser arm attached to the telescope structure. The arm has been designed to control the correct alignment between laser and telescope. It is based in a XY-table (see **Figure 7**), designed to point with a precision better than 1 mm at 1 m distance. To move the two axes, two DC motors are attached to a screw, one per degree of freedom. The motors are of model *Faulhaber* 3863H024C. Attached to them, a 111:1 reduction is used to improve the resolution. Both components perform the movement through screws (1 cm/rev). These are controlled by a *Faulhaber* MCDC3006S driver and an encoder of type *Faulhaber* HEDL5540 on each axis. Finally, to fix the initial position of the table, two end-switches are used. To control all the laser arm, a control board with ethernet interface has been developed.

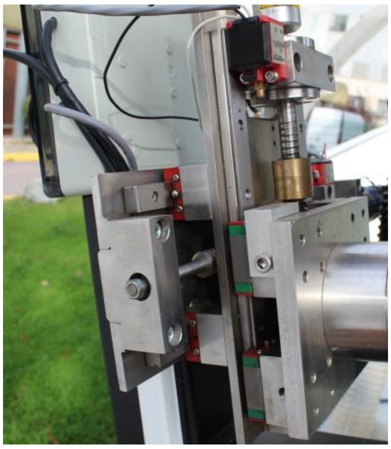


Figure 7: Photograph of the XY-table.

6.2.6 Guiding Mirrors

The dichroic guiding mirrors have been designed such that they resist high laser power, have high reflectivity for the 355 nm and 532 nm wavelengths, but very low reflectivity at 1064 nm (see **Figure 8**). This characteristic is important to protect the liquid light guide against strong infrared light that can damage it.

Given the space restrictions inside the container, they cannot be installed such as to reflect light perpendicularly, but instead under an angle of 61.1 ± 0.3°. The dichroic mirrors have been specifically designed for that reflection angle (**Figure 8** and **Figure 9**).

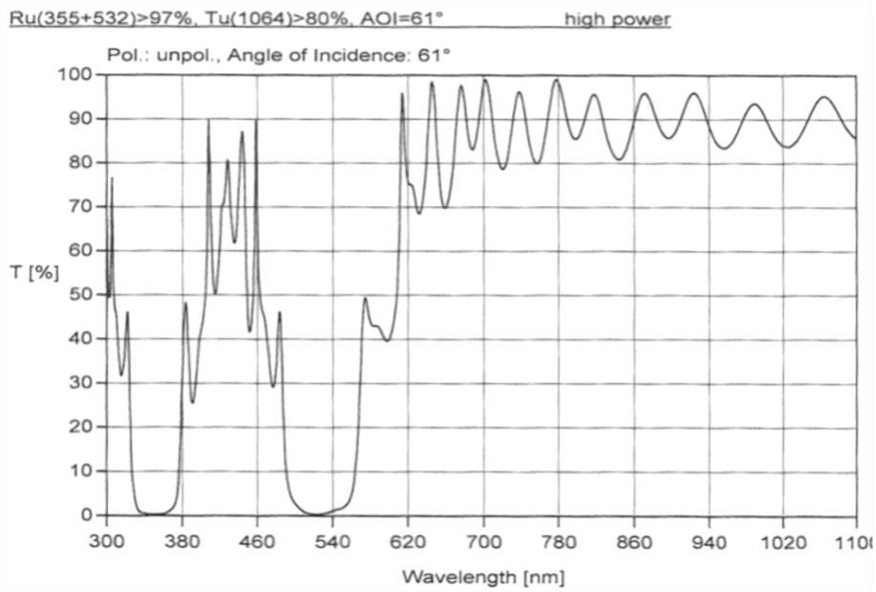


Figure 8: Transmission of the guiding mirrors as a function of wavelength.

Figure 9: Photographs of the guiding mirrors.

6.3 The Laser

The laser used in the IFAE-UAB Raman LIDAR is a Brilliant Nd:YAG 1064nm, from *QUANTEL* company. It is a pulsed 20 Hz laser whose ground wavelength is 1064 nm (Energy per pulse 400 mJ). A second and third harmonic generator at 532 nm (200 mJ per pulse) and 355 nm (100 mJ per pulse) have been added to the main body of the laser.

The harmonic generation is made with highly deuterated KD*P crystals cut at the proper angle for required wavelengths. Each crystal is temperature stabilized in a sealed-off cell ensuring long term energy stability. Cell windows are anti-reflection coated at the appropriate wavelengths. **Table 1** lists the main characteristics of the laser.

Pulse repetition rate	10 Hz	nominal up to 20 Hz
Power drift	3%	over 8 hours
Pointing stability	<75 μrad	
Jitter (1064 nm)	± 0.5 ns	measured at half-width of 500 accumulate shots
Beam divergence (1064 nm)	0.5 mrad	full angle, 85% of total energy, however latest measurements yielded factor 2 worse performance.
Beam diameter (1064 nm)	6 mm	at output of laser
Housing	dust free	
Temperature	actively stabilized	
Energy per pulse (532 nm)	160 mJ	nominal, own measurements yielded 128 mJ.
Energy per pulse (355 nm)	70 mJ	
Pulse duration	4 ns	
Energy stability (shot-to-shot)	<6%	

Table 1: Characteristics of the Quantel Brilliant Laser

6.3.1 Laser Head and Harmonics Generators

The laser has two harmonic generators apart from the main 1064nm wavelength generator. They are assembled in compact modules, including the non-linear crystals and a removable set of dichroic mirrors (see **Figure 10**). Phase matching for the second and third harmonics is obtained by simple mechanical adjustment.

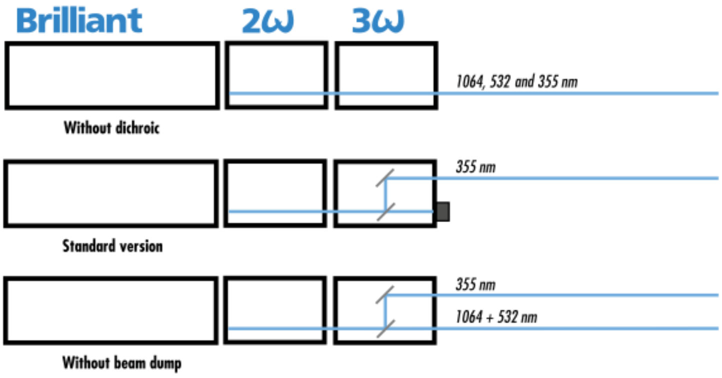


Figure 10: Different harmonic configuration for the laser output.

It is possible to generate frequency doubled and tripled output: after removing the dichroic mirror inside the main body, it is possible to obtain the three wavelengths from the same output hole; however there is no configuration which allows to output only the second and third harmonic at the same hole.

Figure 11: Photograph of the laser mounted on the arm. The output hole is visible within the black area. On top, the (black) heating unit is seen.

6.3.2 Cooling Unit and Heating System

Since the laser is rated to operation according to the *specifications for the beam quality* only at temperatures above 18°C, the system has been equipped with a heating system (see **Figure 11**). The *Leister Hotwind System* provides hot air at a selectable temperature and air volume flow. The hot air can be guided both to the laser cooling group unit (see **Figure 12**) and the laser head through a walve. The water temperature of the cooling unit is read remotely and used to initiate and stop the heating process.

Figure 12: Photograph of the laser cooling group unit

6.4 The Receiver Optics

6.4.1 Liquid Light Guide

A 3.2 m long liquid-light-guide (LLG) of type Lumatec Series 300 (part nr. 4003.3200), 8 mm diameter, is used to transport the light from the focal plane to the polychromator unit. Peak transmission values of up to 80% can be obtained. This type is optimized for the spectral range from 320 nm to 650 nm, within which radiation is transmitted without optical degradation. Nominal and measured transmittances are shown in **Figure 13**.

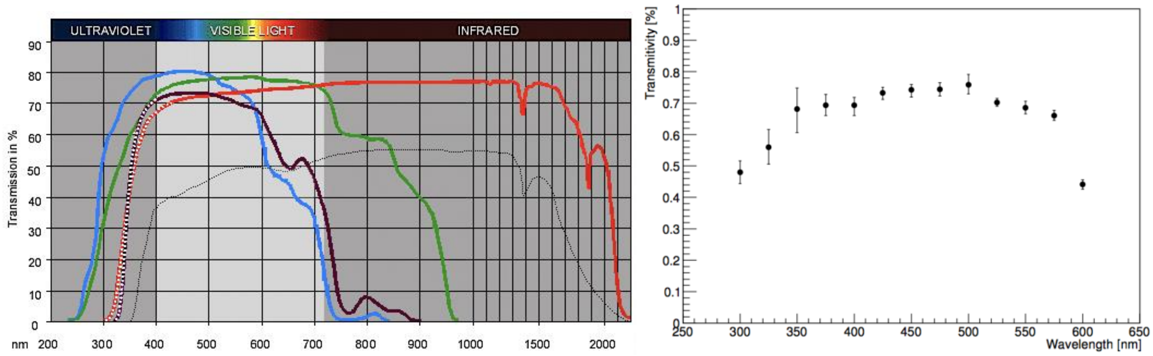


Figure 13: Left: Spectral characteristics of several Lumatec liquid lightguides. The Series 300 is shown in blue for a length of 2000 mm. For comparison, a glass fibre bundle is shown as black dotted line, right: measured transmissivity of 3.2 m LLG.

The liquids inside the LLG are stable over years if the LLG is not exposed to radiation below 320 nm or above 650 nm. Shorter wavelengths may destroy the transmission property of the liquid, longer wavelengths may overheat the liquid and cause bubbles.

Several measurements have been made in the laboratory [4] to test the variation of transmissivity of the LLG with temperature, under different conditions: next to 0° C, at room temperature, at slightly higher temperatures, and for different wavelengths. From these measurements we can conclude that the transmissivity of the LLG barely varies with temperature, being extremely stable at low temperature values. There is a small decrease when reaching higher temperatures ($\geq$25° C). The maximum transmissivity has been found around 23° C.

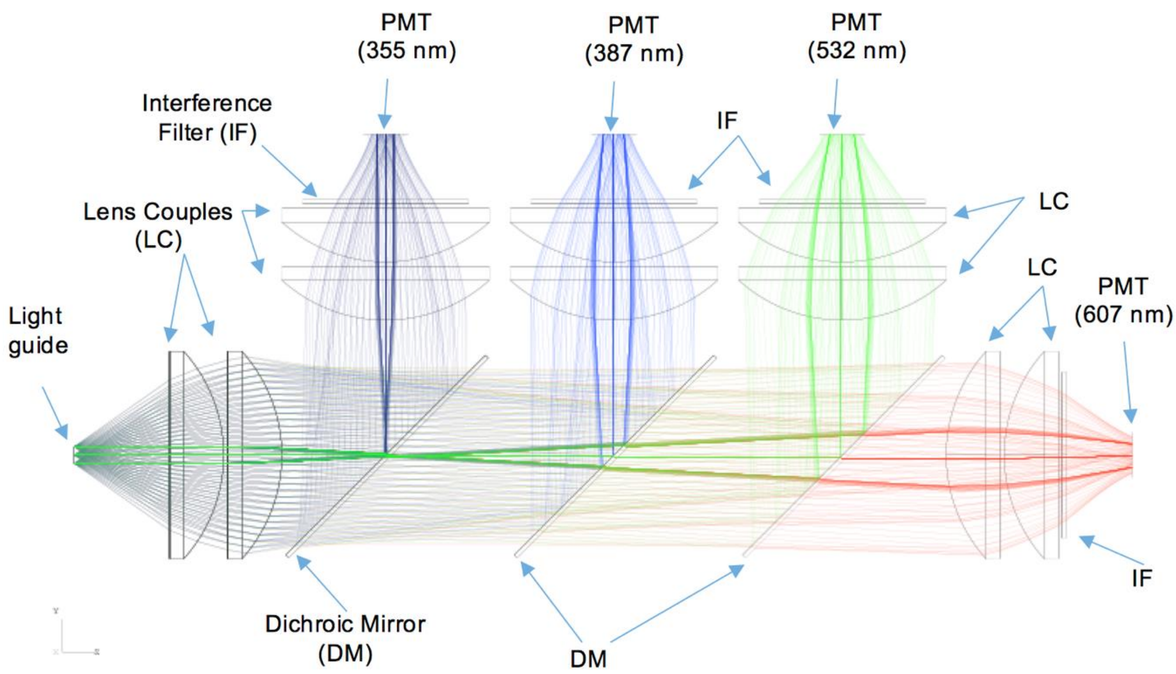
Since the maximum incidence angle of reflected light into the LLG is $\sim$30°, it is important that light coming from angles >30° is *not* transmitted through the LLG in order to reduce background. The LLG has a numerical aperture of 72°, matching perfectly these requirements. Measurements have also revealed a linear relation between light input and output angles, as expected. For more information, see [4].

6.4.2 Polychromator

The Barcelona Raman lidar currently foresees 4 read-out channels: two to analyze the elastic-backscatter light at 355 and 532 nm and two for the Raman Nitrogen backscattered light, at 387 and 607 nm, respectively.

The polychromator unit has been designed in collaboration with the CNR Institute for Photonics and Nanotechnologies in Padova, Italy [5]. The *Zemax* design and a photograph of the equipped polychromator are shown in **Figure 14.**

In **Figure 15** (left), the footprint of 5 sample points, one at the center and four at the edges of the input optical fiber, are shown together with a circle corresponding to the 22 mm active area of the PMT detector. In **Figure 15** (right), the fraction of the image enclosed energy calculated for a uniform circular object of 8 mm in diameter, such as the input fiber, is shown. The total energy emitted by the fiber is collected and focalized on the PMT area.



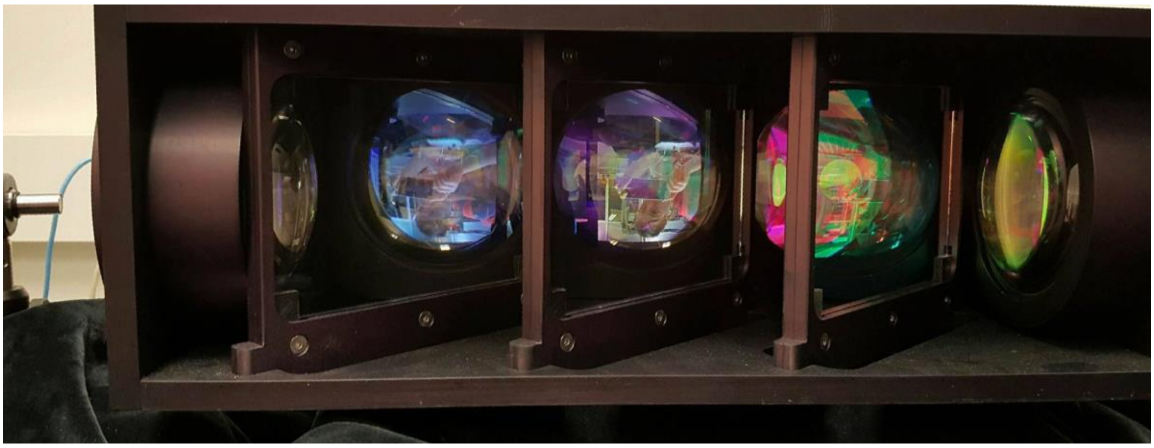


Figure 14: Top: the Zemax design of the Barcelona LIDAR polychromator. Bottom: A picture of the polychromator taken from the bottom side. After collimation of by 100 mm Lens Couples (LC), the in-coming light is directed towards its respective detector with the help of three Dichroic Mirrors (DM). In each channel, the light is again focused by LCs and noise-reduced by 10 nm wide Interference Filters (IFs). Finally, each of the four wavelengths is collected by a 1.5-inch high-quantum-efficiency PMT of type Hamamatsu R11920, the same as those used for the Large-Sized-Telescope (LST) camera.

After all the individual characterization tests of every pieces, careful light leakage tests were carried out. Light produced by a stabilized Xenon lamp passes through a collimator and a set of filters. Wavelengths selected by a monochromator are transmitted to the polychromator through an automatic shutter and the LLG. Ten thousand of measurements were taken for each wavelength in open and closed mode in order to subtract the background and to achieve statistically significant results. Light leakage from outside the polychromator box and between the channels were tested. Leakage from the elastic into the Raman channel could be excluded to be larger than 2×10^{-7}.

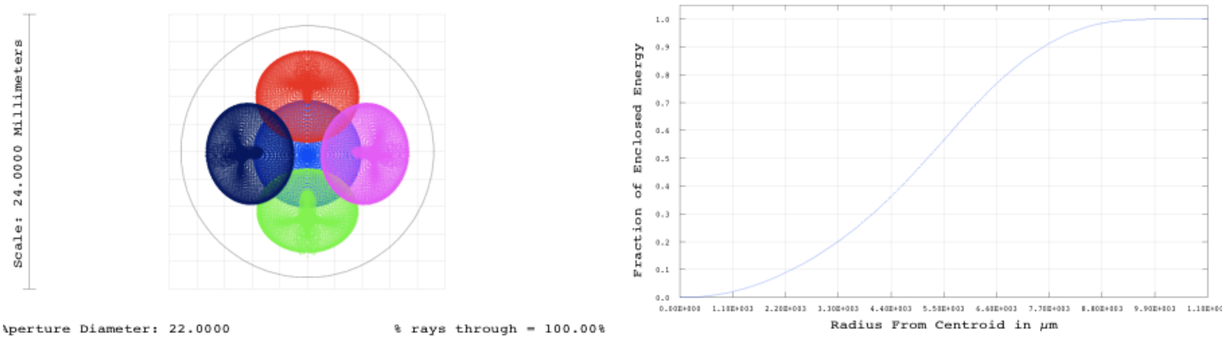


Figure 15: Left: footprint diagram of the PMT active area. Right: encircled energy diagram of the PMT active area.

6.4.3 Near-range Optics

A dedicated near-range optics has been developed to further increase the dynamic range of the system and access the altitude range from ground to about 200 m, where normally most of the aerosols are found. That solution combines a collimator of type RC12SMA-F01 from *Thorlabs* with a standard 1.5 mm fibre. For the moment, the near-range light will be registered by only one PMT, of the same type as those used for the polychromator, in a small "monochromator" box, which uses just one interference filter for the elastic 532 nm line.

6.5 Readout System

The *Licel* Optical Transient Recorder is a powerful data acquisition system, especially designed for remote sensing applications, reaching the best dynamic range together with high temporal resolution at fast signal repetition rates.

Analog detection of the photomultiplier current and single photon counting is combined in one acquisition system. The combination of a 12-bit A/D converter (at 40 MHz) with a 250 MHz fast photon counting system increases the dynamic range of the acquired signal averaging is performed by specially designed ASICs. A high-speed data interface to the host computer allows readout of the acquired signal even between two laser shots.

The Transient Recorder is comprised of a fast-transient digitizer with onboard signal averaging, a discriminator for single photon detection and a multichannel scaler combined with preamplifiers for both systems. For analog detection the signal is amplified according to the input range selected and digitized by a 12-bit-20/40 MHz A/D converter. A hardware adder is used to write the summed signal into a 24-bit wide RAM. At the same time the signal part in the high frequency domain is amplified and a 250 MHz fast discriminator detects single photon events above the selected threshold voltage. 64 different discriminator levels and two different settings of the preamplifier can be selected by using the acquisition software supplied. The photon-counting signal is written to a 16-bit wide summation RAM which allows averaging of up to 4094 acquisition cycles. The photon counting acquisition system includes a fast three-stage preamplifier and a discriminator with 64 threshold levels, controlled by the host computer. A time resolution of 50 ns without any dead time or overlap between two memory bins is reached by using a continuous counter together with a multichannel scaler burnt into the silicon of a custom designed ASIC.

The *Licel* transient recorder is completely software controlled. Input ranges for analog and photon counting acquisition, discriminator levels and the number of active bins can be selected. The acquired analog and photon counting signals for both summation memories can be read out separately. Data are transferred via a 2x16 bit interface to a National Instruments DIO-32-HS family (PC) interface card. Up to 16 Transient recorders can be controlled by one interface card, in our case only two are currently operating, but three are foreseen for the Pathfinder LIDAR. The final version will contain six transient recorders.

6.6 The Control Hardware

The Barcelona Raman LIDAR is currently controlled through three separated control networks: One connecting the container doors and the telescope, another controlling the laser, the laser arm with its XY-table, and the polychromator and finally the *Licel* data acquisition unit. The first two use micro-controllers, whereas the third is treated as a stand-alone system. All three interface directly by clients and can be locally and remotely controlled. An industrial PC hosts, among others, the control software and allows to operate the LIDAR directly from within the container.

Moreover, a key switch is installed to allow local operation without any possible interference from remote.

At a later stage and once standards have been established for auxiliary CTA instrument control, the micro-controllers will be replaced by a dedicated safety-PLC and interfaced through OPC-UA.

6.7 The Control Software

Dedicated low-level control software has been written in *java*. The software is virtualized through the use of *Docker* containers. A server operates as a bridge between the observatory network and the internal LIDAR network, such that only required ports are kept open. Only authenticated users have access to the control software.

6.7.1 Foreseen Operation Modes

The operation mode of the Raman LIDAR for CTA, together with other atmospheric calibration devices, has been described in [6]. That scheme requires, however, full integration of the LIDAR into the CTA Array Control and Data Acquisition (ACADA) and the Laser Traffic Control System (LTCS), installed at the Observatorio del Roque de los Muchachos (ORM).

For that reason, the Raman LIDAR *Pathfinder* will follow a simplified operation scheme, suitable for its participation in the current *cross-calibration* campaign: Instruments participating in the campaign characterize the atmosphere towards the zenith 10 minutes before and after the start of astronomical twilight. Only for dedicated tests, such as performance tests under different zenith angles, the Raman LIDAR *Pathfinder* may operate under different conditions and at different times. Such timely limited tests will be communicated to the observatory well in advance and ask for permission by potentially affected instruments, among which the LST1.

6.7.2 Data Rates

A typical LIDAR data set accumulates 100 seconds (i.e. 1000 laser pulses) of data. Each data set has then a size of about 200 kB. Given the foreseen preliminary operations during twilight only, the Raman LIDAR will hence produce less than 5 MB a day.

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[3] Baillon, P. et al. (1989). Production of 300 paraboloidal mirrors with high reflectivity for use in the Barrel RICH counter in DELPHI at LEP, NIM A 277(2), 338-346.
[4] López-Oramas, A. (2014). Multi-year Campaign of the Gamma-Ray Binary LS I +61°303 and Search for VHE Emission from Gamma-Ray Binary Candidates with the MAGIC Telescopes, Phd Thesis, Universitat Autònoma de Barcelona.
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7 Safety

To ensure that the Raman LIDAR operates safely, the following safety measures have been taken:

E-stops: 3 Emergency push-buttons have been installed, two inside the container and one outside.

Remote/site operation: A key switch has been installed to ensure that operators can work with safety when they are inside the container, the site operation mode selection (by means of the key switch) ensures that LIDAR cannot be operated remotely.

Laser shooting: A switch ensures that the laser can only be shoot if its zenith angle is between 0º and 60º, that is, the zenith angle range between 60º and 90º is forbidden, such that the laser cannot be shoot if someone stands just in front of it.

Safety baffle: An anodized baffle has been installed, which protects the surrounding from spurious directed laser light during the LIDAR alignment procedure.

Parking position switches: As explained in § 6.1.1, the container doors cannot be moved, if the telescope is not in parking position.

Container door access: A position sensor ensures that the Container doors cannot be moved unless the container access door is closed.

Fence: The container doors' opening/closing is a hazardous situation, which shall be eliminated by installing a fence that prevents anyone to be exposed to this situation.

Labelling: Safety signs have been stuck on the Raman LIDAR to inform about correct behaviour in situations that may be dangerous.

PPE: The LIDAR carries all necessary personal protection equipment (PPE), like safety gloves, helmet, googles and boots.

Documentation: The Raman LIDAR will be delivered with all the relevant documentation. Reading of this documentation is mandatory.

Training: Apart from being obliged to read all the relevant documentation, the Raman LIDAR users must receive a dedicated safety training.