The IFAE/UAB Raman LIDAR for the CTA-North

AtmoHEAD 2018

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for the CTA Consortium (see www.cta-observatory.org)
The IFAE/UAB Raman LIDAR

Outline

• CTA atmospheric characterization of observed fields-of-view
• The design of the IFAE/UAB Raman LIDAR
• First commissioning results
• Future plans
Atmospheric characterization of the observed line-of-sight view by CTA
Characterization of observed field-of-view

Requirements for systematic uncertainties on energy scale, due to atmospheric effects, are very ambitious.

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<th>comments</th>
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Introduction to CTA

- Gamma-ray precision astronomy and astrophysics from 50 GeV to 100+ TeV
- Introduction to CTA
- Sites climatology
- Characterization of observed fields-of-view
- Atmospheric characterization for dynamic scheduling
- Weather monitoring

Imaging Atmospheric Cherenkov Telescopes

Very High Energy (VHE) gamma-ray $E \sim O(0.1 - 100 \text{ TeV})$

Particle shower

Cherenkov light

Gamma-ray direction

Telescopes

Cameras 1 and 2

~ 300 m
Introduction to CTA

Imaging Atmospheric Cherenkov Telescopes

Very High Energy (VHE) gamma-ray $E \sim O(0.1 - 100$ TeV)

Atmosphere used as a calorimeter
Need to continuously characterize:

1. The profile from ground to 25 km distance
   - GDAS/ECMWF (see P. Munar, Monday)
   - Raman LIDARs

2. The extension of clouds across the FOV of 10°, determination of time slots with equal atm. conditions
   - FRAM (see P. Janecek, Tuesday)

3. For cross-checks:
   - The Cherenkov Transparency Coefficient (see S. Stefanik, Tuesday)
Characterization of observed field-of-view

Need to continuously characterize:

1. The profile from ground to 25 km distance
   • GDAS/ECMWF
   • Raman LIDARs

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   • The Cherenkov Transparency Coefficient

Instruments and analysis algorithms determine:
- Intervals of stable atmospheric conditions
- Corrections for the Instrument Response Functions
- Associated statistical and syst. uncertainties
Correction of the instrument IRF

Tessellated VAOD maps (from FRAM)

Time (e.g. 25 min.)

Altitude

Altitude

Time (e.g. 25 min.)

Syst. Error limit

Syst. Error limit

+ CTC

8 km

8 km

2.5 km

2.5 km

Decision to stop TI

Decision to stop TI
Requirements for a CTA Raman LIDAR

Need to continuously characterize:

1. The profile from ground to 25 km distance
   • Raman LIDARs

2. The extension of clouds across the FOV of 10°, determination of time slots under equal conditions
   • FRAM

3. For cross-checks:
   • The Cherenkov Transparency Coefficient

- Full characterization of the atmosphere up to 25 km distance, within 1 minute with Raman capabilities.
- Full sky coverage up to 60° zenith angle.
- At least 2 lines within sensitive window of the CTA photo-detectors
- Characterization of ground-layer aerosols
- Low distance to full overlap range
- Inclusion to CTA internal communication
- OPC-UA compatible communication, standard CTA states
- Low maintenance and failure rates
- Safe operation
Need to continuously characterize:

1. The profile from ground to 25 km distance
   • Raman LIDARs

- Recycle former CLUE telescope and container 1.8 m (!) parabolic mirror

- 2 + 2 configuration:
  - 355 nm + 532 nm elastic lines
  - 387 nm + 607 nm N₂ Raman lines

- Laser: Brilliant Compact Q-Switched Nd:YAG 1064nm + frequency tripler head
  Rate: 20 Hz
  Pulse: 5 ns
  Beam divergence: 0.5 mrad

- Dichroic guiding mirrors → coaxial

- Polychromator in-house

- Acquisition: standard LICEL units

- Dedicated near-range optics and readout
Need to continuously characterize:

1. The profile from ground to 25 km distance
   • Raman LIDARs
2. The extension of clouds across the FOV of 10°, determination of time slots under equal conditions
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3. For cross-checks:
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Chosen solution for the IFAE/UAB design

- CEILAP LIDAR
- LUPM LIDAR
- IFAE/UAB LIDAR
  • Recycle former CLUE telescope and container
    1.8m parabolic mirror
    2 + 2 configuration:
    • 355 nm + 532 nm elastic lines
    • 387 nm + 607 nm N₂ Raman lines
  • Atmospheric molecular and aerosol transparency as a function of range and wavelength.
  • Laser: Brilliant Compact Q-Switched Nd:YAG 1064 nm + frequency tripler head
    Rate: 10 Hz
    Pulse: 5 ns
    Beam divergence: 0.5 mrad
  • Dichroic guiding mirrors à coaxial
  • Polychromator home made
  • Acquisition: standard LICEL units
Need to continuously characterize:

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Chosen solution for the IFAE/UAB design

IFAE/UAB LIDAR

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Chosen solution for the IFAE/UAB design

Polychromator

Large aperture telescope and PSF of 6 mm require 100 mm ≠ optics in polychromator

Diagram showing the components of the polychromator system, including PMT, interference filters, lens couples, dichroic mirrors, and light guides.
Need to continuously characterize:

1. The profile from ground to 25 km distance
   - Raman LIDARs

2. The extension of clouds across the FOV of 10°, determination of time slots under equal conditions
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3. For cross-checks:
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Polychromator was designed by CNR Padova and built by at IFAE workshop

Chosen solution for the IFAE/UAB design

Polychromator

- PMT (355 nm)
- PMT (387 nm)
- PMT (532 nm)
- PMT (607 nm)
- Interference Filter (IF)
- Lens Couples (LC)
- Dichroic Mirror (DM)
- Light guide
Need to continuously characterize:

1. The profile from ground to 25 km distance
   - Raman LIDAR

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Chosen solution for the IFAE/UAB design

Polychromator

Light leakage from any elastic to any Raman channel $< 2 \times 10^{-7}$ (!)
Link budget study for sensitivity

- Sensitivity is limited by the two Raman lines
- Should reach 15 km within less than one minute
“First light” results

Currently reach within 50 seconds and 10 Hz trigger rate:

- 40 km with elastic lines
- 10 km with 387 nm Raman lines

Sensitivity can be further improved by:

- Raising laser frequency to 20 Hz
- Cleaning the primary mirror
Full overlap is reached at ≈150 m:

- for elastic lines with reduced gain
- for all Raman lines

Sensitivity to the near field can be further improved by:

- Dedicated near-range optics and readout (in preparation)
**“First light” results**

Full overlap is reached at $\approx 150$ m:

- for elastic lines with reduced gain
- for all Raman lines

Sensitivity to the near field can be further improved by:

- Dedicated near-range optics and readout (in preparation)

*Very low quantum efficiency of 607 nm PMT still!*
Location of the ORM
Conclusions

• During operation of CTA need to characterize the line-of-sight, across a $10^\circ$ field-of-view.

• Requirements on systematic uncertainties are very ambitious, in order to make CTA a precision tool.

• Large aperture Raman LIDAR with powerful laser

• Basic design works now!

• Commissioning work still ongoing (part of it will be carried out at La Palma in 2019)
Thank you!
Backup
Architecture of control software

- CTA Array Control (ACTL)
- LIDAR Online Analysis Software
- LIDAR Data
- LIDAR State Machine
- LIDAR Server
- LIDAR Online Analysis Software
- LICEL Drivers
- LIDAR Hardware Drivers
- Original LICEL LabView Code
- Mock LICEL Hardware (Java)
- Mock LICEL DAQ (Java)
- LICEL Transient Recorders
- Original LIDAR LabView Code
- For Testing Only

LIDAR Hardware (C & VHDL Firmware)

- Laser Control
- PMT High Voltage Control
- Mirror Pointing Motors
- Container Open/Close Motors
- Environmental Sensors
PMT characterization

- 4 PMTs needed in the polychromator: -2 for the elastic channels (355nm and 532nm) -2 for the Raman channels (387nm and 607nm)

- 4 Hamamatsu R11920-100 high quantum efficiency PMTs available: ZQ6623, ZQ5819, ZQ6627, ZQ6622

\[ C = QE \times HV\text{-dependent}\text{-gain} \]
Experimental setup

→ use of a calibrated Newport 818-UV PIN photodiode

→ V=1200V (chosen arbitrarily)
Results

- Increment the wavelength by 10nm (±2nm) from 300nm to 600nm
- Measure of the PMT current with the shutter open (closed)
- Subtraction of the background from the PMT measurements
- Comparison with the PIN-diode subtracted-background data (PIN-diode data multiplied by the PMT QE and ND filter transmission)

Elastic channels
- 355nm → ZQ5819
- 387nm → ZQ6622
- 532nm → ZQ6623
- 607nm → ZQ6627
Characterization of the polychromator response

Test set up

- He lamp
- Colimator
- Filter wheel
- Monochromator
- Shutter
- Liquid light guide
- Polychromator
- PIN diode
Status prototype

Hardware

✅ • Mirror characterized
✅ • Liquid light guide characterized
✅ • Guiding mirrors (dichroic)

Design of the guiding mirrors

Transmission vs. wavelength

(see Bc thesis Eudald Font Pladevall)
Status prototype

Hardware

- Mirror characterized
- Liquid light guide characterized

Transmission vs. wavelength

Output angle vs. input angle

(see PhD thesis Alicia López Oramas)
Status prototype

Hardware

✓ • Mirror characterized (using different methods)

Fraction of focused light falling into a circle with radius $x$ from an artificial “star” located at 65 m from the telescope.

(Reflectivity was 64% at 350 nm at that time).

(see PhD thesis Alicia López Oramas)