The Barcelona Raman LIDAR project and its prospects for the CTAO-North

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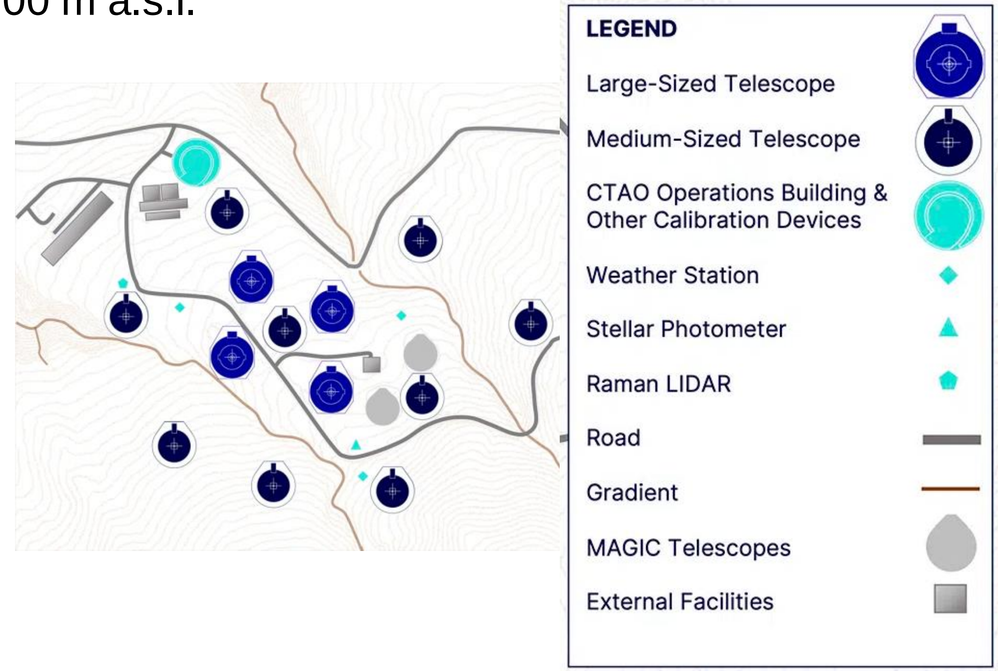
for the BRL team

The Cherenkov Telescope Array Observatory

- CTAO – next-generation observatory for detection of high-energy photons with Imaging Atmospheric Cherenkov Telescopes (IACTs)
  - CTAO-North at the Observatorio del Roque de Los Muchachos (ORM), La Palma, Canary Islands, Spain
    - 13 telescopes spread over 0.6 km^2, 2200 m a.s.l.
  - CTAO-South at a site belonging to the European Southern Observatory (ESO), Cerro Paranal, Chile
    - 58 telescopes spread over 4 km^2, 2100 m a.s.l.

CTAO-North site under construction

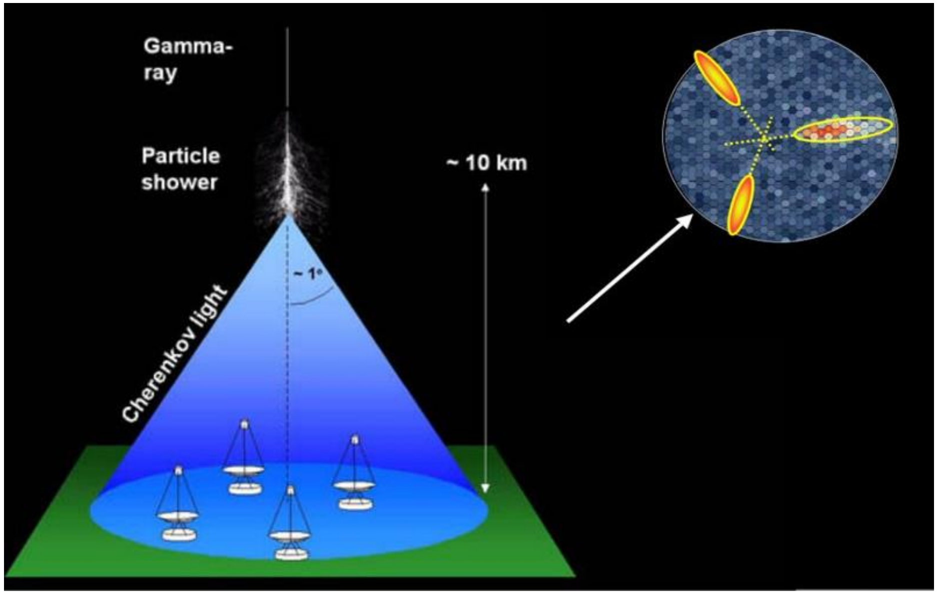


CTAO-North site final layout

Imaging Atmospheric Cherenkov Telescopes

- Indirect detection of individual cosmic photons in the Very High Energy (VHE) regime (tens of GeV – hundreds of TeV)
  - Generation of extended atmospheric showers (EAS) of secondary particles
  - Ultrarelativistic during most of the shower development → emission of Cherenkov radiation with peak at 350 nm
  - Most of the light originates from altitudes from 5 – 20 km → huge illuminated area on the ground (10^5 – 10^6 m^2)

- CTAO will achieve sensitivities for cosmic VHE photon detection, larger by a factor of 5 – 10 (with respect to present experiments)



How IACTs see Cherenkov light

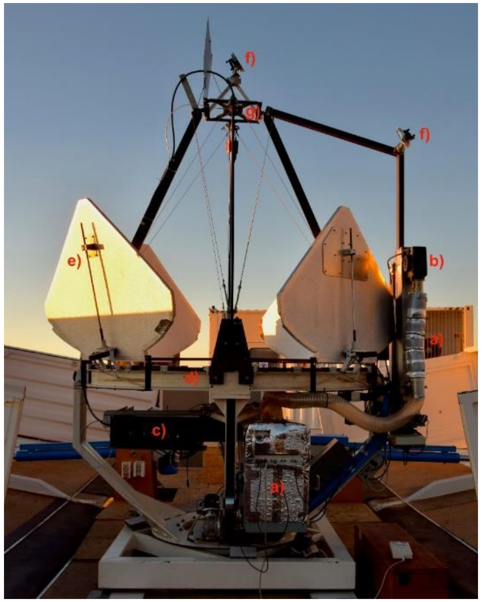
Imaging Atmospheric Cherenkov Telescopes

- IACTs use atmosphere as a calorimeter → series of limitations to the accuracy of the shower energy reconstruction
  - Development of EAS depends on refractive index of air
  - Propagation of Cherenkov light is influenced by atmospheric extinction
- Constant monitoring of aerosol extinction in entire calorimeter volume is required! → LIDAR
  - Only elastic LIDAR – optical depth with an accuracy of ~ 20 %
  - Raman LIDAR – extinction and backscattering coefficient measured simultaneously and independently, with accuracy well bellow 5 %
- CTAO requirements
  - Atmospheric characterization in entire calorimeter volume (vertical range ~ 30 km) at 2 wavelengths between 300 nm and 700 nm
  - Range resolution of ~ 150 m
  - Aerosol/cloud transmission profiles with signal-to-noise ratio (SNR) of 10 in < 1 min

CTAO-North Raman LIDAR Pathfinder

- Designed, maintained and operated in collaboration between:
  - Institut de Física d'Altes Energies (IFAE), Spain
  - Universitat Autònoma de Barcelona (UAB), Spain
  - University of Nova Gorica (UNG), Slovenia
  - Università degli Studi di Padova (UniPd), Italy
  - CTAO gGmbH, Germay
- Timelapse
  - 2017 – first tests of the system at UAB
  - 2019 – awarded the status of a CTAO Pathfinder
  - 2020 – deployed near LST-1 at ORM
  - 2022 – returned to UAB for upgrades (expected to be completed in 2025)

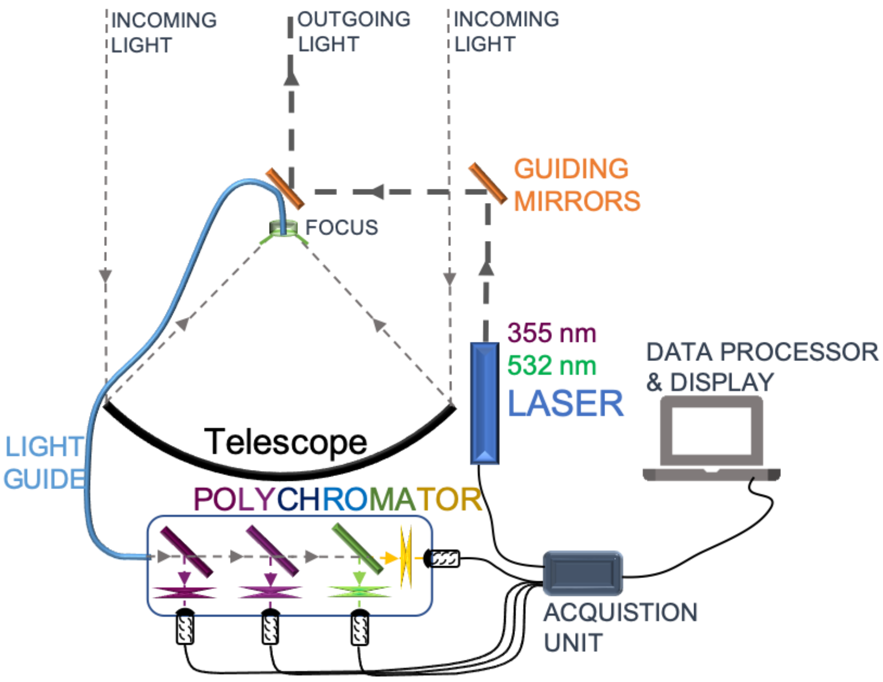
BRL under construction at UAB, 2017



BRL at ORM, 2021

CTAO-North Raman LIDAR Pathfinder - components

- Steerable Alt-Az mount
- Transmitter - Nd:YAG laser
  - 532 nm, max 160 mJ at 10 Hz
  - 355 nm, max 70 mJ at 10 Hz
- Reciever - 1.8 m parabolic mirror
  - *f/D* = 1, from CLUE experiment
- Four steerable petals for sunlight protection
- Liquid light guide
- Spectroscopic filter, three operational channels
  - Two elastic at 355 nm and 532 nm
  - Nitrogen Raman at 387 nm
- Licel based data acqusition (DAQ) software
- 20 ft standard Maritime container

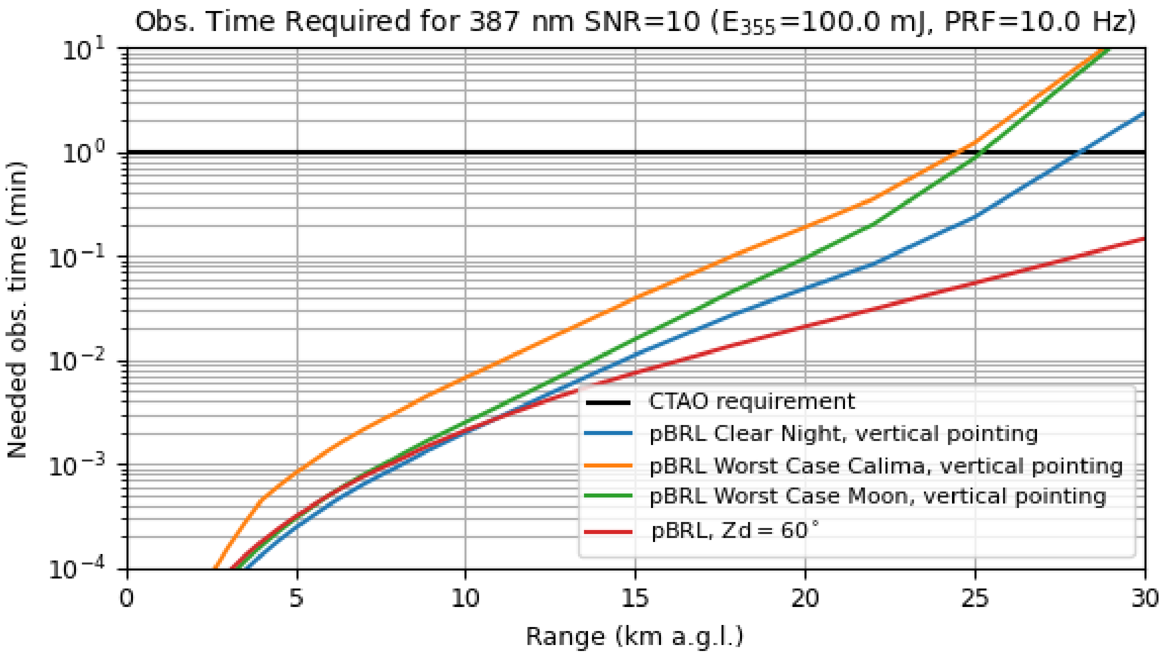


Schematic drawing of the BRL

Performance - UAB Data, simulations

- Simulation of design performance, *python*
  - Calculate expected return power and signal-to-noise ratio (SNR) for single shots at various altitudes, under diferent weather conditions and laser wavelengths

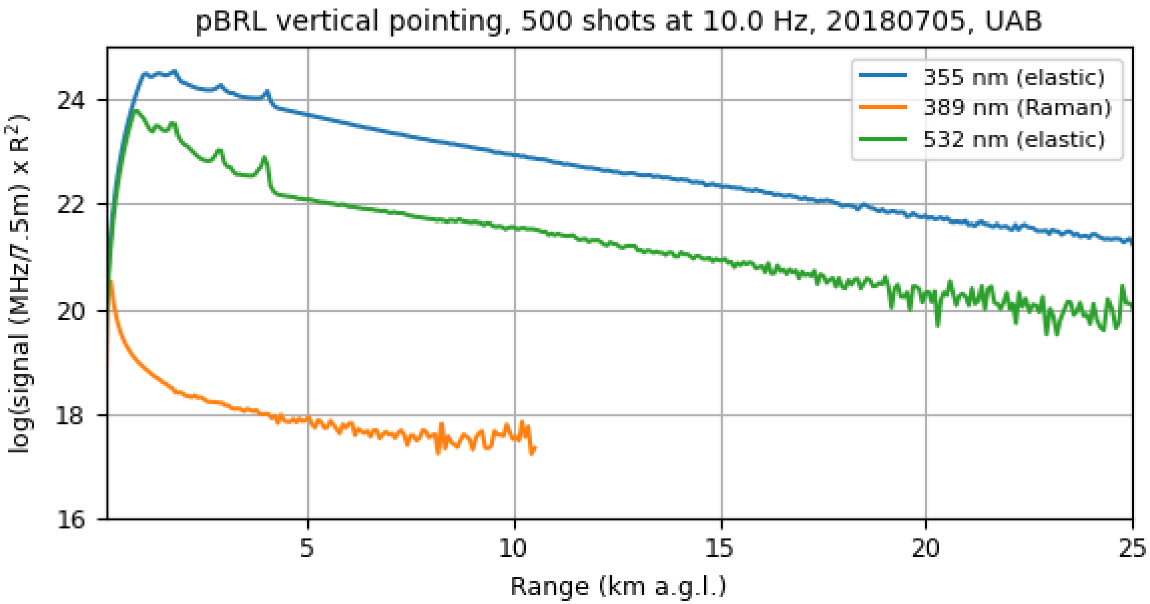
- Time needed to measure the aerosol/cloud transmission profiles with SNR of 10 in few cases (CTAO reqirement is < 1 min)



Time needed for a profile with SNR=10

Performance - UAB Data, measurements

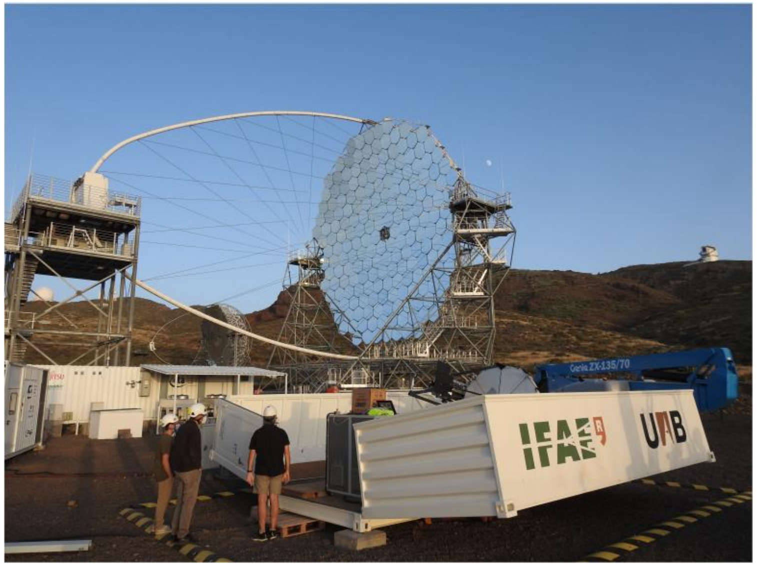
- Maximum detectable range
  - Data taken at UAB during night time in 2017-2019
  - Fully-powered laser, 2 elastic and 1 Raman channel
  - 500 shots at 10 Hz (< 1 min)
  - Analog and photon counting signals connected together, averaged over 75 m
- CTAO requirement is ~ 30 km with SNR>1



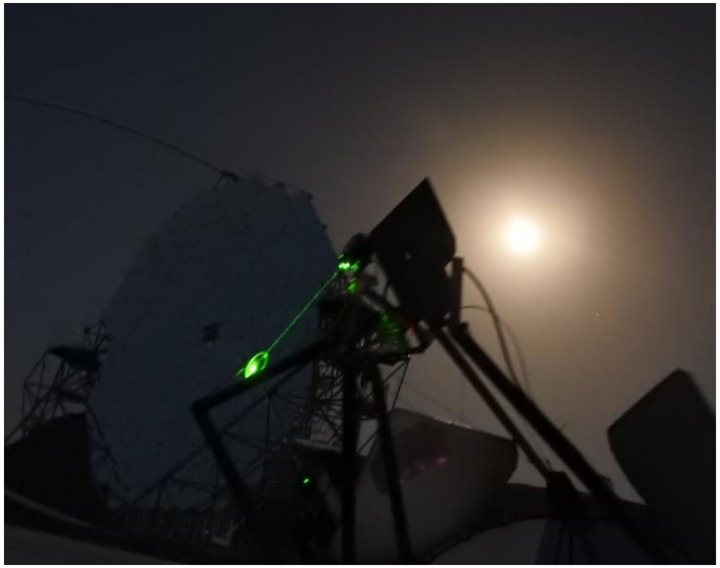
Obtained Lidar return signal

Performance - ORM Data

- Testing at ORM from Feb 2021 to May 2022, next to LST-1
  - Operation constrained to periods of astronomical twilight during full moon nights (BRLs operation not yet included in ORM's Laser Traffic Coordinate System (LTCS))
  - Reduced high voltage on PMTs (PMT gating not yet available)
  - Other minor issues (Tajogaite volcano eruption in September 2021, DAQ software, T < 0 °C)
  - ~ 33 nights, ~ 20 h of data



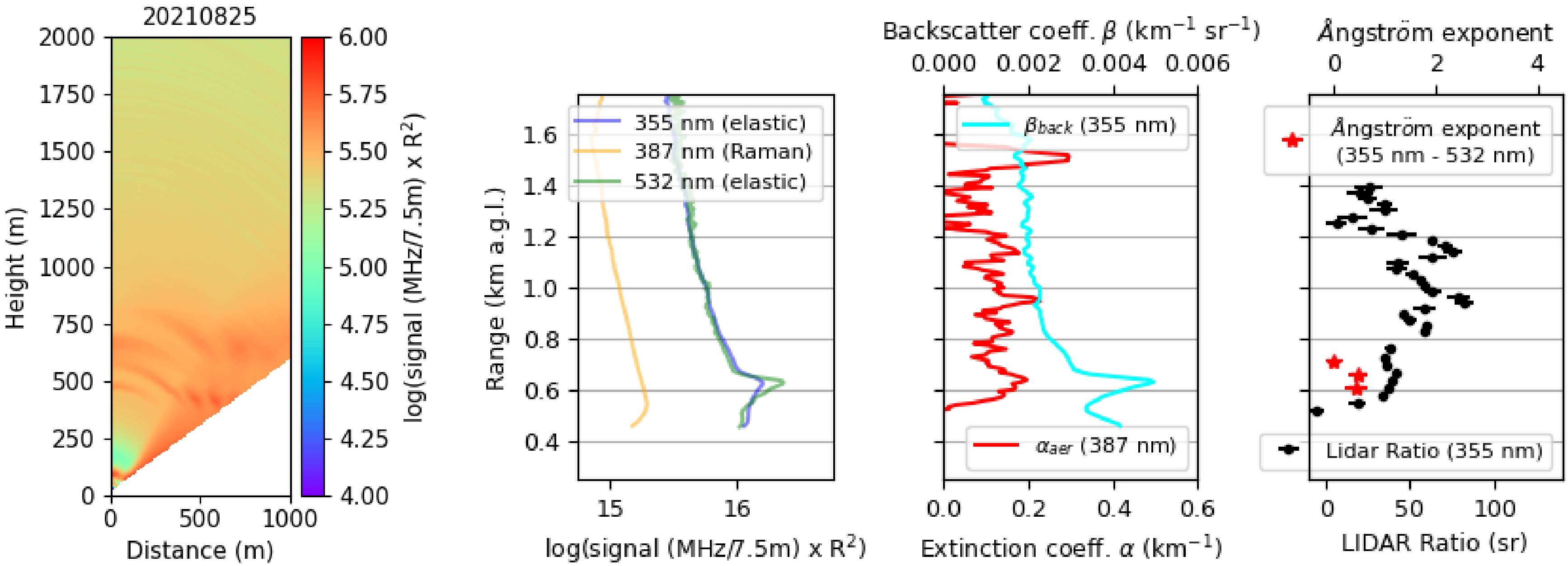
BRL next to LST-1



BRL during measurements

Performance - ORM Data

- Analysis of Lidar data during Calima (4th and 5th week of August 2021)
  - More detailed analysis performed on data from 25 and 26 August 2021
  - Non uniform distribution of dust seen on 25 August
  - Average lidar ratios between 40-50 sr and Ångström exponent below 1.0 imply scattering on large, irregularly shaped particles such as mineral dust



Spatial distribution of aerosol loading on 25 August and aerosol characterization

Conclusions

- Measurements performed at UAB and ORM thought us how to make the BRL meet the strict CTAO requirements for atmospheric characterization
  - A laser with slightly lower power but faster repetition rate (Litron, 50 mJ, 200 Hz)
  - New gated PMTs, adapted to each channel
  - Re-aluminization of main mirror
- Ongoing upgrades will allow BRL to permanently become part of the CTAO-North observatory