ARCADE

Atmospheric Research for Climate and Astroparticle DEtection

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AtmoHEAD Workshop
June 2013

The ARCADE project

F.I.R.B. - Project
Principal Investigator *Laura Valore*
March 2012-2015

MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA

FUTURO IN RICERCA

Scientific Motivations

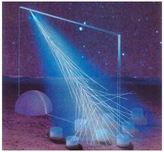
The study of characteristics of atmospheric aerosols is closely related to the understanding of the complex mechanisms that determine the climatic variations of our planet. Aerosols and clouds play also a key role in the observations and study of **High Energy Cosmic Ray** ($E > 10^{12} eV$) and **UHECR** ($E > 10^{18} eV$) from both ground-based and space-based experiments.

Research goals

Characterization of the optical properties of the atmosphere in the near UV and the development of predictive models through measurement campaigns in areas with different environmental characteristics:

- Development of models that describe the stratification of aerosols in the areas of measurement and their dependence on temperature, wind, precipitation, humidity, in collaboration with climatology experts that will apply predictive models to these measurements
- Study of the cloud cover and cloud optical depth
- Comparison of different techniques of analysis used in Cosmic Rays experiments to study aerosol attenuation to highlight their points of strength, limitations and systematics

Atmosphere and Cosmic Rays



How are UHECR detected?

$\Downarrow$

Extensive Air Shower (EAS)

How to measure energy of UHECR?

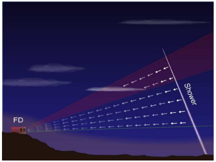
$\Downarrow$

Detection of UV light emitted by de-excitation of N_2 molecules

Atmosphere causes both production and attenuation of UV light

Scattering of light due to aerosols influence the correct determination of the longitudinal development of the shower in air and of its energy.

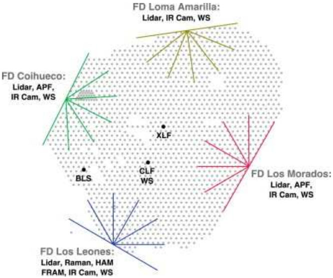
Measurement of aerosol attenuation at different altitudes using Laser-Light Scattering



Typical techniques to study aerosol attenuation

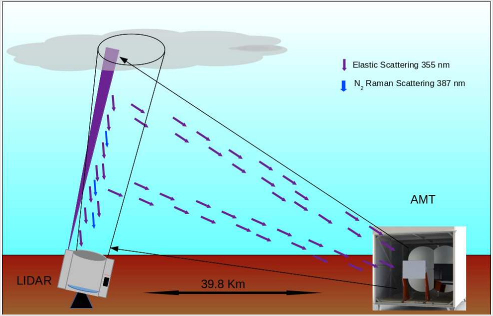
Elastic Back-scattering LIDAR
Side-scattering from a Laser source

PIERRE AUGER OBSERVATORY



Measurement Apparatus

- Side-Scattering from a distant laser facility using a UV detector (AMT)
- Steerable Elastic LIDAR
- Steerable Raman LIDAR



For the first time, all the techniques are compared on the same air mass and at the same time!
No interference with a CR experiment

Side Scattering Measurement

Light Attenuation

$$I(\lambda, s) = I_0(\lambda, s)T_{mol}(\lambda, s)T_{aer}(\lambda, s)(1 + f)(\frac{d\Omega}{4\pi})$$

$$T_{aer}(\lambda, s) = e^{-\int \alpha_{aer}(\lambda,s)ds} = e^{-\frac{VAOD(h)}{sen(\phi)}}$$

$\alpha_{aer}(\lambda, s)$=aerosol extinction coefficient

Analysis techniques

- Laser Simulation Analysis
  Compares measured profiles with a parametric simulations of the aerosol attenuation vertical profiles
  $$VAOD(h_2 - h_1) = \frac{H_{aer}}{L_{aer}}\left(e^{-\frac{h_1}{H_{aer}}} - e^{-\frac{h_2}{H_{aer}}}\right)$$
- Data Normalized Analysis
  Comparison of measured light profiles with a reference night in which the aerosol attenuation is negligible

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Elastic Lidar

LIDAR Equation

$$P(\lambda, z) = \frac{K(\lambda)}{z^2} \cdot \beta(\lambda, z) \cdot e^{-\int \alpha(\lambda,s)dz}$$

$\alpha(\lambda, s)$= extinction coefficient, $\beta(\lambda, s)$= back-scattering coefficient

Assumption

Klett Method - Aerosol Lidar Ratio

$$L = \frac{\alpha_{aer}(z)}{\beta_{aer}(z)}$$

Multiangle Analysis

$$S(r, r_0) = ln[\frac{P(r)r^2}{P(r_0)r_0^2}] = ln\frac{\beta(r)}{\beta(r_0)} - 2\tau(r, r_0)$$

$$S(h, \xi) = ln\frac{\beta(h)}{\beta(h_0)} - 2\xi\tau(h, h_0)$$

with $h = rcos(\theta)$ and $\xi = sec(\theta)$

$$\longrightarrow \tau(h, h_0) = -\frac{1}{2}\frac{\delta S}{\delta \xi}$$

Assumption

Depends on the assumption of a perfect horizontal uniformity of the optical properties of the atmosphere

Raman LIDAR

$$P(\lambda_{N_2}, z) = \frac{K(\lambda_{N_2})}{z^2} \cdot \beta(\lambda_{N_2}, z) \cdot e^{-\int [\alpha(\lambda_0,s)+\alpha(\lambda_0,s)]dz}$$

Assumption

Need to assume an analytical dependence of the aerosol attenuation coefficient at different wavelengths λ_0 and λ_{N_2}

$$\frac{\alpha_{aer}(\lambda_0)}{\alpha_{aer}(\lambda_{N_2})} = \left(\frac{\lambda_{N_2}}{\lambda_0}\right)^{å}$$

Not based on assumptions of atmospheric properties (LIDAR ratio, horizontal homogeneity, ...)

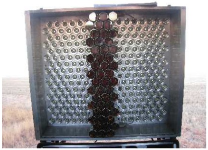
BUT

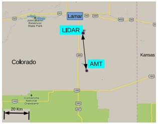
Great interference in the field of view of Fluorescence Detectors due to the long time needed for acquisition

Auger $\longrightarrow$ CLF Upgrade!

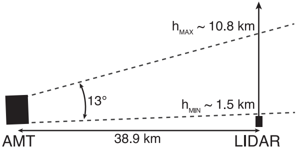
AMT Atmospheric Monitoring Telescope

Already existing facility owned by the Colorado School of Mines



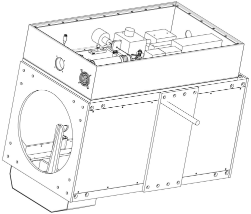


- 39.8 Km far from the laser source for side-scattering measurement
- 3.5 m^2 mirror (HiRes Optics)
- 3 columns of 16 PMT

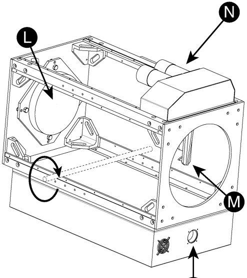


LIDAR LIght Detection And Ranging

New Costruction

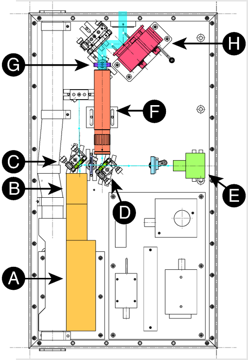


- Steerable (Alt mount)
- Laser: Quantel Centurion Nd:YAG, UV light at 355 nm $\sim$ 6 mJ
- Diameter 25 cm, f/3 parabolic mirror
- Elastic and N_2 Raman channels
- Overlap function = 1 @ 250 m



- I - Laser beam exit
- L - Primary parabolic mirror
- M - Secondary flat mirror
- N - Raman box

LIDAR LIght Detection And Ranging



Laser Bench

- A - Laser ($\phi = 1.6$ mm , div$=$ 3 mrad)
- B, C - Dichroic mirrors
- D - Beam Splitter (95/5)
- E - Laser Probe
- F - 10X beam expander
- G - Depolarizer
- H - Motorized mirror mount

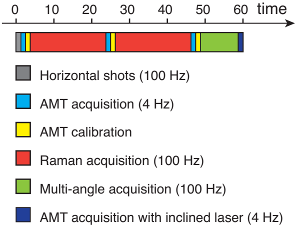
Operation

Horizontal shots towards the AMT

Check the horizontal uniformity at ground level

- ↦ estimate the distance at which the signal starts to be analyzable, i.e. where the overlap function becomes constant
- ↦ measure the horizontal aerosol attenuation length $\alpha_{aer}(0)$

Automatic measurements throughout the night

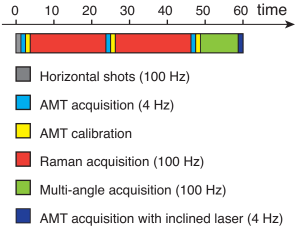


Operation

Inclined shots towards the AMT

Check the horizontal uniformity from the comparison with vertical shots measurements

Automatic measurements throughout the night



Analysis Techniques

AMT

- Laser Simulation Analysis $\longrightarrow$ development of parametric model that takes into account the PBL
- Data Normalized Analysis

LIDAR

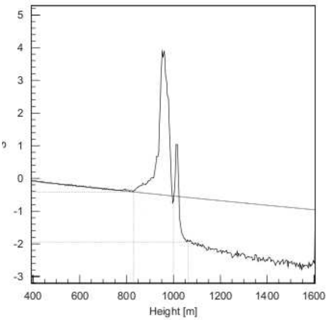
- Elastic Multiangle Analisys
- Raman Analysis

Measurement on the same air mass and in the same time

Cloud cover and cloud optical depth measurement

Clouds distort the light measurement

Can block the UV light, causing a dip in the light profile, or reflect more light in the detector FOV, enhancing the collected light



Measurements of cloud cover, altitude, and cloud optical properties can be performed with both devices. In particular, the lidar can identify multiple cloud layers.

Information from vertical and inclined shots will be compared with satellite data

Climatology Implications

Aerosols play a key role in atmospheric radiative processes

$\downarrow$

Considerable effect on climate

Systematical measurements made by ARCADE together with satellite observations will be used to develop more comprehensive and predictive models and determine the evolution of meteorological fields and aerosol concentration in atmosphere.

Project steps

- Costruction of the LIDAR, last steps
- Improvement of data acquisition system and calibration system of AMT
- Re-installation of the camera and tests of AMT
- LIDAR: Test and first measurements in Italy, in urban (Turin) and rural areas (CETEMPS, L'Aquila)
- One year nightly data taking in Lamar, Colorado, arid environment

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$$\boxed{\text{Thank you}}$$

Backup

H_{aer} = aerosol scale height factor
L_{aer} = aerosol horizontal attenuation length

$$\alpha_{aer}(h) = \frac{1}{L_{aer}} \cdot e^{-\frac{h}{H_{aer}}}$$