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Applying H.E.S.S. Lidar profiles on Crab Nebula data and their impact

Author: Justine Devin[1]

Co-authors: George Vasileiadis [1]; Johan Bregeon [1]; Yves Gallant [1]

[1] *LUPM*

Corresponding Author: george.vasileiadis@lupm.in2p3.fr

The H.E.S.S. experiment in Namibia, Africa, is a high energy gamma ray telescope sensitive in the energy range from 100 Gev to a few tens of TeV, that uses the atmospheric Cherenkov technique to detect showers developed within the atmosphere. To minimize the systematic errors on the derived fluxes and energy dependencies of the measured sources, using a Lidar one can calculate the impact of the atmospheric properties, in particular the extinction parameter of the Cherenkov light ($300–650 nm). The later has a direct impact on the above estimations. In this paper we report on physics results obtained using measured spectra of the Crab nebula using Lidar profiles obtained at the H.E.S.S. site. A brief extrapolation also on the performance of the future CTA project and the use of Lidars are also given.

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Monitoring of Night Sky UV Radiation by One-pixel Detector

Author: Simon Mackovjak[1]

Co-authors: Igor Strhárský [1]; Ján Baláž [1]; Marián Putiš [1]; Pavol Bobík [1]

[1] *Department of Space Physics, Institute of Experimental Physics, Slovak Academy of Sciences*

Corresponding Author: simon.mackovjak@gmail.com

The night time UV radiation composed of airglow, starlight, and zodiacal light act as a background for detection of the Extensive Air Shower (EAS) fluorescence induced by Ultra-High Energy Cosmic Rays (UHECR). To monitor this background, we have developed the one-pixel instrument that provides the absolute intensities within the spectral range 300 - 480 nm in the one second temporal resolution. The instrument is designed to be unpretending, resistant, and to operate in full automatic mode. Therefore it could be placed in various locations and provide long-therm measurements. The first results from four such instruments demonstrate that the data might be useful not only for the high-energy astrophysics purposes but also for the studies of the airglow dynamics.

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Propagation and R.F. Emission Patterns of Lightning Leaders as Observed by the LOFAR Radio Telescope

Author: Brian Hare[1]

Co-authors: Anna Nelles [2]; Arthur Corstanje [3]; Bonardi Antonio [3]; Falcke Heino [2]; Gia Trinh [1]; Jorg Horandel [3]; Jorg Rachen [3]; Mitra Pragati [4]; Olaf Scholten [5]; Pim Schellart [3]; Rossetto L [3]; Sander ter Veen [6]; Stijn Buitink [4]; Thoudam Satyendra [3]; Tobias Winchen [4]; Ute Ebert [7]

[1] *University of Groningen*

[2] university of Nijmegen

[3] University of Nijmegen

[4] University of Brussels

[5] KVI/University of Groningen

[6] ASTRON

[7] CWI

Corresponding Author: b.h.hare@rug.nl

LOFAR (LOw Frequency ARray) is a radio telescope that consists of a large number of dual-polarized antennas spread over the northern Netherlands and beyond. The LOFAR for Lightning Imaging project (LOFAR-LIM) has successfully used LOFAR to map out lightning in the Netherlands. Since LOFAR covers a large frequency range (10-90 MHz), has antennas spread over a large area, and saves the raw trace data from the antennas, LOFAR-LIM can combine all the strongest aspects of both lightning mapping arrays and lightning interferometers. These aspects include a nanosecond resolution between pulses, nanosecond timing accuracy, and an ability to map lightning in all 3 spatial dimensions and time. LOFAR should be able to map out overhead lightning with a spatial accuracy on the order of meters.

We will present an intra-cloud flash and a cloud-to-ground flash that have been mapped using a new 3-dimensional interferometric technique. These maps contain enough detail that fast processes, such as recoil leaders and even return strokes, can be mapped in full 3 dimensions. We will also show intensity and polarization footprints of RF pulses received from stepped leaders and discuss the implications for the propagation physics of stepped leaders.

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Producing realistic atmopsheres for radio simulations of extensive air showers using GDAS

Author: PRAGATI MITRA[1]

[1] *Vrije Universiteit Brussel*

Corresponding Author: pmitra@vub.be

The LOFAR radio telescope measures the radio emission from extensive air showers with unprecedented precision. Estimating the depth of shower
maximum Xmax with higher precision is of great interest for the study of primary particle composition. One of the major systematic uncertainties in reconstructing X_max is due to limited knowledge of the refractive index of air and its dependence on humidity, pressure, and temperature. This calls for the inclusion of real atmospheric data at the time of the air shower at a given observational site into the monte carlo air shower simulation codes like CORSIKA/CoREAS. Using The Global Data Assimilation System(GDAS), a global atmospheric model based on meteorological measurements and numerical weather predictions we have implemented realistic refractive index along with real time atmospheric profiles in CORSIKA/Coreas, which is available since the latest release. We present the results from re-analyzing LOFAR cosmic-ray data with new improved atmospheres.

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Ground-Based Observations of Terrestrial Gamma Ray Flashes Associated with Downward-Directed Lightning Leaders

Author: Rasha Abbasi[1]

Co-authors: J. belz [1]; P. Krehbiel [2]; TA/LMA collaboration for the [3]; W. Rison [2]

[1] *University of Utah*

[2] *Langmuir Laboratory for Atmospheric Research, New Mexico Institute of Mining and Technology*

[3] ,

Corresponding Author: rasha@cosmic.utah.edu

Terrestrial gamma-ray flashes (TGFs) are bursts of gamma-rays initiated in the Earth's atmosphere. TGFs were serendipitously first observed over twenty years ago by the BATSE gamma ray satellite experiment. Since then, several satellite experiments have shown that TGFs are produced in the upward negative breakdown stage at the start of intracloud lightning discharges. In this talk, we present the ground-based first observation of TGFs, and show that TGFs are also produced by the downward negative breakdown occurring at the beginning of negative cloud-to-ground flashes.

The Terrestrial gamma-ray flashes discussed in this work were detected between 2014-2017 at ground level by
the Telescope Array surface detector (TASD) together with Lightning Mapping Array (LMA) and the slow electric field antenna (SA).
The TASD detector is a ~700~km^2 ultra high energy cosmic ray detector in the southwestern desert of Utah. It is comprised of 507 (3~m^2) plastic scintillator detectors on a 1.2~km square grid. The LMA detector, a three-dimensional total lightning location system, is comprised of nine stations located within and around the array. The slow electric field antenna records the electric field change in lightning discharges.

The observed Gamma ray showers were detected in the first 1-2 ms of downward negative breakdown prior to cloud-to-ground lightning strikes. The shower sources were observed by the LMA detector at XSaltitudes of a few kilometers or less above ground level. The detected energetic burst showers have a footprint on the ground typically $\sim$ 3–5~km in diameter. The bursts comprise of several (2-5) individual pulses, each of which have a span of a few to tens of microseconds and an overall duration of several hundred microseconds. Using a forward-beamed cone of half-angle of 16^{circle}, GEANT simulation studies indicate that the showers are consistent with gamma rays of $10^{12} - 10^{14}$ primary photons. We hypothesize that the observed terrestrial gamma-ray flashes are similar to those detected by satellites, but that the ground-based observations are closer to the source and therefore are able to observe weaker sources and report on the structure of the temporal distribution at the source. This result and future studies will enable us to better identify and constrain the mechanisms of downward TGF production.

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The Observation of lightning-related events with the Surface Detector of the Pierre Auger Observatory.

Author: Roberta Colalillo[1]

[1] *NA*

Corresponding Author: roberta.colalillo@na.infn.it

The Pierre Auger Observatory, designed to detect ultra high energy cosmic rays, can be a valid instrument at ground to study phenomena related to the atmospheric electricity. The fluorescence detector is a powerful instrument to observe elves thanks to its excellent time resolution, while peculiar events with a large number of triggered stations have been recorded by the surface detector. The characteristic signal of these events lasts more than 10 µs, about two order of magnitude more than the duration of a signal produced by a cosmic muon. Moreover, each of these events has at least one station with signal dominated by high frequency noise that could be related with a lightning-induced signal.
Stations with a long-lasting signal are arranged in a disk shape. There are "big"events characterized by a radius of about 6 km and few "small"events with a radius of about 2-3 km. The signal, generated

by a source very close to the ground, first reaches the innermost stations and then spreads outwards. In the "big"events, a lack of signal in some of the central stations was observed.
Further studies and checks are in progress to understand the origin of the lack of signal and what mechanisms occuring during the lightning evolution may provide for electric fields capable of generating and accelerating particles that can produce Cherenkov light in the stations of the surface detector.

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Atmospheric monitoring using the Cherenkov Transparency Coefficient for the Cherenkov Telescope Array

Author: Stanislav Stefanik[1]

Co-author: Dalibor Nosek [1]

[1] *Charles University, Prague*

Corresponding Author: stefanik@ipnp.troja.mff.cuni.cz

The Cherenkov Telescope Array (CTA), the future ground-based gamma-ray observatory, will require reliable monitoring of the atmosphere which is an inherent part of the detector. We discuss here the implementation of the extended method of the Cherenkov Transparency Coefficient for the atmospheric calibration for the CTA. The method estimates the atmospheric transmission of Cherenkov light, relying on the measurement of the rates of cosmic ray-induced air showers that trigger different pairs of telescopes. We examine the performance of our approach utilizing Monte Carlo simulations assuming various atmospheric conditions and CTA observation configurations.

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12 years of aerosol profile measurements at the Pierre Auger Observatory with CLF and XLF

Author: Laura Valore[1]

[1] *NA*

Corresponding Author: laura.valore@na.infn.it

Aerosol attenuation profiles of the UV light have been measured at the Pierre Auger Observatory since the very beginning, dating back to 2004. The Central Laser Facility is operational since 2004, and its twin, the eXtreme Laser Facility, is operational since late 2010.
Two techniques are applied to produce the hourly aerosol attenuation profiles that are continuously used in the data analysis of the Fluorescence Detector of the Observatory to take into account the rapidly varying aerosol load in the atmosphere during the data taking. Neglecting the presence of aerosols leads to underestimation of the primary energy on average by 8%, with variations of single events reaching 40%.
In this contribution, 12 years of aerosol attenuation profiles measured using the data from the two laser facilities are presented, as well as the improvements in the analysis techniques.

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Atmospheric Monitoring at a Cosmic Ray Observatory –a long-lasting endeavour

Author: Bianca Keilhauer[1]

[1] *Karlsruhe Institute of Technology KIT*

Corresponding Author: bianca.keilhauer@kit.edu

The Pierre Auger Observatory for detecting ultra-high energy cosmic rays has been founded in 1999. After a main planning and construction phase of about five years, the regular data taking started in 2004, but it took another four years until the full surface detector array was deployed. In parallel to the main detectors of the Observatory, a comprehensive set of instruments for monitoring the atmospheric conditions above the array was developed and installed as varying atmospheric conditions influence the development and detection of extensive air showers.
The multitude of atmospheric monitoring installations at the Pierre Auger Observatory will be presented as well as the challenges and efforts to run such instruments for several decades.

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On The Importance Of The Electrical And High-Energy Processes Monitoring In Troposphere

Author: Arsen Ghalumyan[1]

Co-authors: Ashot Chilingaryan [2]; Johannes Knapp [3]; Karen Apresyan [4]; Meri Zazyan [2]; Vardan Ghazaryan [2]

[1] *A. Alikhanian National Laboratory (Yerevan Physics Institute), Armenia, 0036, Alikhanian Br. Str. 2*

[2] *A Alikhanyan National Lab (Yerevan Physics Institute)*

[3] *Deutsches Elektronen-Synchrotron, Zeuthen, Germany.*

[4] *A. Alikhanyan National Lab (Yerevan Physics Institute), Yerevan,*

Corresponding Author: ghalumyan@yandex.ru

The upcoming Cherenkov Telescope Array (CTA) project is expected to provide unprecedented sensitivity in the low-energy (<~100 GeV) range for Cherenkov telescopes. In order to fully exploit the potential of the telescope systems it is meaningful to look for ways to further improve the available analysis methods and include possible biasness of the Cherenkov images due to the influence of the atmospheric electric processes.A LIDAR system for the continuous monitoring of the troposphere above the CTA site is proposed as a solution of mentioned above problem. The reflected from clouds return profiles will be sensitive to the polarization of the elastic backscattered signal. At present, the system is being tuned for measuring vertical atmospheric backscatter profiles of aerosols and hydrometeors, analyze the depolarization ratio of elastic backscattered laser beams and investigate the influence of external factors on the beam polarization. In this paper, we describe the first measurements of polarization separated LIDAR return profiles and depolarization ratio profile in the atmosphere and clouds by means of our LIDAR system.

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The use of aerosol data in Auger Fluorescence Detector analysis

Author: Bruce Dawson[1]

[1] *University of Adelaide*

Corresponding Author: bruce.dawson@adelaide.edu.au

The Pierre Auger Observatory's Fluorescence Detector (FD) consists of 27 optical telescopes arranged in four sites around the perimeter of the 3000 square kilometre Surface Detector (SD). Cosmic ray extensive air showers are viewed via the nitrogen fluorescence light they induce in the atmosphere. Careful treatment of light attenuation processes must be made, especially given that some showers are viewed at distances in excess of 30 km. Of particular importance is the attenuation due to scattering by aerosol particles, a challenging topic given that aerosol concentrations can vary on time-scales of hours. At the Auger Observatory, the vertical distribution of aerosols is measured hourly with a series of bi-static lidar systems (consisting of central laser facilities and each of the FD sites), and three times per night with a Raman lidar system. In this contribution we describe the use of aerosol profiles in the analysis of air shower data, in particular in the estimation of the cosmic ray primary energy, and the depth of shower maximum, Xmax. We also demonstrate how statistical and systematic uncertainties in the aerosol concentrations propagate through to a contribution to energy and Xmax uncertainties.

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The Auger Raman Lidar: several years of continuous observations.

Author: Vincenzo Rizi[1]

[1] *GSGC*

Corresponding Author: vincenzo.rizi@aquila.infn.it

The Raman lidar (RL) at the Central (Raman) Laser Facility of the Pierre Auger Observatory in Argentina, has been operational since September 2013.
In this talk, the Auger RL performance is discussed in terms of the data quality for the assessment of the aerosol contribution to the atmospheric UV optical transparency, and how much this is important for the reconstruction of the UHECR properties, based on the Auger Fluorescence Detector observations.

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The Raman LIDAR for the pre-production phase of CTA.

Author: Marco Iarlori[1]

[1] *LNGS*

This talk presents the ARCADE Raman lidar that has been tested and validated at L'Aquila before the deployment at CTA North site.
The performances and the limitation of Raman lidar (RL) technique are also discussed:
- the technical constrains of RL systems;
- the strategy of the observations at ORM site;
- the main signal analysis issues, i.e., how to estimate VAOD profiles, and data significance (errors

and resolution).
Some final comments and conclusions are clearly outlined.

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Analysis of atmospheric attenuation using the Telescope Array central laser data

Author: Tareq AbuZayyad[1]

[1] *University of Utah*

Corresponding Author: tareq@cosmic.utah.edu

Located in the western desert of the state of Utah, the Telescope Array (TA) experiment measures the properties of ultra high energy cosmic ray (UHECR) induced extensive air showers. TA employs a hybrid detector comprised of a large surface array of scintillator detectors overlooked by three fluorescence telescopes stations. The TA Low Energy extension (TALE) detector has operated as a monocular Cherenkov/fluorescence detector for nearly five years, and has recently been complemented by a closely spaced surface array to operate in hybrid mode. The TAx4 upgrade is underway and aims to, as the name suggests, quadruple the size of the surface array to improve statistics at the highest energies (post-GZK events).

The analysis of the TA fluorescence detectors (FD) data requires knowledge of the degree of the atmospheric attenuation of UV light produced by shower particles. This attenuation depends partially on the amount of aerosols present in the atmosphere at the time of shower observation. Being highly variable, real time measurement of the aerosols light attenuation is accomplished through the use of a central laser facility (CLF) located at the center of the surface array, and in the field of view of the three FDs, as well as, the TALE FD.

In this talk we will describe the experiment and it's various upgrades, the CLF station, and the CLF data and analysis. We will briefly describe other atmospheric monitoring systems used by TA. Finally we will present plans for TAx4 atmospheric calibration.

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The IFAE/UAB Raman LIDAR for the CTA-N

Author: Markus Gaug[1]

Co-authors: Camilla Maggio [1]; Guiteras Font [1]; Manel Martinez [2]; Merve Sidika Colak [2]; Michele Doro [3]; Oscar Blanch Bigas [2]; Pere Munar-Adrover [4]; Òscar Martinez [2]

[1] *Universitat Autònoma de Barcelona and IEEC-CERES*

[2] *IFAE*

[3] *PD*

[4] *Universitat Autònoma de Barcelona*

The IFAE/UAB Raman LIDAR project aims to develop a Raman LIDAR suitable for the online atmospheric calibration along the line-of-sight of the Northern array of the CTA.
Requirements for such a solution include the ability to characterize aerosol extinction to distances of 30 m with an accuracy better than 5%, within time scales of less than 1 minute.
The Raman LIDAR consists therefore of a large 1.8m mirror and powerful pulsed Nd-YAG laser. A liquid light-guide collects the light at the focal plane and transports it to the readout system.

An in-house built polychromator has been characterized thoroughly with respect to its capability to efficiently separate the different wavelengths (355nm, 387nm, 532nm and 607nm). It was found to operate according to specifications, particularly light leakage from the elastic channels (532nm and 355nm) into the much dimmer Raman channels (387 nm and 607nm) could be excluded to at least less than 10^-5.
We present here the status of the integration and commissioning of this solution and its plans for the near future.
After a one-year test period at the Observatorio del Roque de los Muchachos, an in-depth evaluation of this and the solutions adopted by a similar project developed by the LUPM, Montpellier, will lead to a final Raman LIDAR proposed to be built for both CTA sites.

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Studying molecular profiles above the Cherenkov Telescope Array sites

Author: Pere Munar-Adrover[1]

Co-author: Markus Gaug [2]

[1] *INAF-IAPS*

[2] *IAC*

Cherenkov Telescope Array (CTA) will bring a whole new insight to the gamma-ray Universe. In order to fulfill its performance requirements we need to understand and correct the atmospheric effects that influence the acquired instrument data. For this reason we have studied atmospheric molecular profiles above both CTA sites, La Palma and Cerro Armazones, using publicly available historical data assimilation archives. Our study reveals that we can distinguish at least three differentiated epochs at the northern site and at least two at the southern site, if we want to model the molecular part of the atmosphere using average profiles, as with current Cherenkov telescope projects. Seasonal transitions are smoother in the southern than in the northern site, moreover the latter shows a greater amplitude in density variations at an altitude of 15 km, where variations are generally larger.
We explored also the deviations in the molecular profiles with respect to the mean value in a 6 year data set and saw that they are always within within the CTA site atmospheric requirements.

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Aerosol Optical Depth from MODIS satellite data above the Pierre Auger Observatory

Author: Nataliia Borodai[1]

[1] *Institute of Nuclear Physics PAN, Krakow*

Corresponding Author: nataliia.borodai@ifj.edu.pl

Aerosol optical depth can be retrieved from measurements performed by Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument. The MODIS satellite system includes two polar satellites, Terra and Aqua. Each of them flies over the Pierre Auger Observatory once a day, providing two measurements of aerosols per day and covering the whole area of the Observatory. MODIS aerosol data products have been generated by three dedicated algorithms over bright and dark land and over ocean surface. We choose the Deep Blue algorithm data to investigate the distribution of aerosols over the Observatory, as this algorithm is the most appropriate one for semi-arid land of the Pierre Auger Observatory. This data algorithm allows us to obtain aerosol optical depth (AOD)

values for the investigated region. Quality cuts were also applied to the data. As a result, cloud-free aerosol maps were prepared with the horizontal resolution 0.1° × 0.1°. Since a sufficient number of measurements was obtained only for Loma Amarilla and Coihueco FD sites of the Pierre Auger Observatory, a more detailed analysis of aerosol distributions is provided for these sites, i.e. we prepared daily plots for the years 2004-2017. Aerosols over these FD sites are generally distributed in a similar way each year, but some anomalies are also observed. These anomalies in aerosol distributions appear mainly due to some transient events, such as volcanic ash clouds, fires etc. Some seasonal effects are also observed. We conclude that the Deep Blue MODIS algorithm provides more realistic aerosol optical depth values than other algorithms, although the uncertainties, both systematic and statistical, are still essential.

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Atmospheric monitoring with the Fluorescence detector Array of Single-pixel Telescopes

Author: Dusan Mandat[1]

Co-authors: Ladislav Chytka [2]; Max Malacari [3]; Petr Hamal [2]; Toshihiro FUJII [4]

[1] *Institute of Physics Academy of Sciences of the Czech Republic*

[2] *Joint Laboratory of Optics of Palacky University Olomouc*

[3] *Kavli Institute for Cosmological Physics*

[4] *ICRR, University of Tokyo*

Corresponding Author: mandat@fzu.cz

The Fluorescence detector Array of Single-pixel Telescopes (FAST) is a proposed low-cost, large-area, next-generation experiment for the detection of ultrahigh-energy cosmic rays (UHECRs) via the atmospheric fluorescence technique. Two FAST telescopes are installed and operating at the Black Rock Mesa site of the Telescope Array Experiment in Utah, USA. Knowledge of the properties of the atmosphere above the detector is of utmost importance for the analysis and reconstruction of the energy and trajectory of UHECRs measured with an atmospheric fluorescence telescope. The FAST experiment uses all sky camera (FASTCam) and sky quality monitor (SQM) for the detection of clouds and quantification of the night-sky background light in the field-of-view of the telescopes. Measurements of a vertically-fired ultra-violet laser at a distance of 21 km from the FAST telescopes are used to infer the transparency of the atmosphere above the detector via comparison with simulations.

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Update on the Atmospheric Monitoring at the MAGIC Site

Author: Martin Will[1]

[1] *Max-Planck-Institut für Physik*

Corresponding Author: mwill@mpp.mpg.de

The MAGIC telescopes in La Palma, Canary Islands, measure Cherenkov light emitted by gamma-ray induced air showers in the atmosphere. For the correct and safe operations of the telescopes, but most importantly for the subsequent data analysis, the knowledge of the atmospheric parameters is important. Corrections to the measured data can be applied after analyzing the atmospheric monitoring data.

The atmospheric monitoring program at the MAGIC site includes several devices, reliably characterizing the atmosphere above the telescopes for many years. Currently some smaller upgrades are made, especially regarding the determination of the atmospheric transmission at very high zenith angles using stellar spectroscopy.

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ELVES at the Pierre Auger Observatory

Author: Roberto Mussa[1]

[1] *TO*

Since 2013, the Pierre Auger Observatory, located in Malargue (Argentina), has implemented a dedicated trigger for the study of
transient luminous emissions from the base of the ionosphere. These phenomena, called ELVES, are due to the de-excitation of the nitrogen
molecules after the passage of the electromagnetic pulses produced by strong lightning activity. A significant fraction of the ELVES events are double
or even multiple, and their interpretation is quite controversial. This report will review the reconstruction and parametrization of such events
using the last five years of data taken by the Observatory.

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New developments in aerosol measurements using stellar photometry

Author: Jan Ebr[1]

[1] *Institue of Physics, Prague*

Corresponding Author: janebr@email.cz

The idea of using stellar photometry for atmospheric monitoring for optical experiments in high-energy astrophysics is seemingly straightforward, but reaching high precision of the order of 0.01 in the determination of the vertical aerosol optical depth (VAOD) has proven consistently difficult. Wide-field photometry in a large span of altitudes allows fast determination of VAOD independently of the absolute calibration of the system, while providing this calibration as a useful by-product. Using several years of data taken by the FRAM telescope at the Pierre Auger Observatory in Argentina and about a year of data taken by a similar instrument deployed at the planned site of the Cherenkov Telescope Array in Chile, we have developed calibration and analysis methods to improve the precision of this measurement technique towards and possibly beyond the 0.01 mark. Detailed laboratory measurements of the response of the whole system to both the spectrum and intensity of incoming light have proven indispensable in this analysis as the usual assumption of linearity of the CCD detectors is not sufficiently valid for the conditions of the observations.

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FRAM telescopes and their measurements of aerosol content at the Pierre Auger Observatory and at future sites of the Cherenkov Telescope Array

Author: Petr Janecek[1]

[1] *Institute of Physics AS CR*

Corresponding Author: janecekp@fzu.cz

A FRAM telescope is a system consisting of a robotic mount, a large-format CCD camera and a fast telephoto lens that can be used for atmospheric monitoring at any site whenever information about the atmospheric transparency is required with high spatial or temporal resolution and where continuous use of laser-based methods for this purpose would interfere with other bservations. The original FRAM has been operand at the Pierre Auger Observatory in Argentina for more than a decade, while three more FRAMs are foreseen to be used by the Cherenkov telescope array (CTA). The CTA FRAMs are being deployed ahead of time to characterize the properties of the sites in advance of the operation of the CTA Cherenkov telescopes; one FRAM has been running on the planned future CTA site in Chile for a year while two others are expected to enter operation before the end of 2018. We report on the hardware and current status of operation and/or deployment of all the FRAM instruments in question as well as on some of the preliminary results of integral aerosol measurements by the FRAMs in Argentina and Chile.

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Influence of Atmospheric Electricity on the recovered parameters of primary cosmic rays

Author: Ashot Chilingaryan[1]

[1] *Yerevan Physics Institute*

The problem of thundercloud electrification is of the most difficult ones in the atmospheric physics. The structure of electric fields in the cloud escapes from the detailed in situ measurements; few balloon flights revealed rather complicated structure that is much more sophisticated than a simple dipole or tripole models. To get insight into the problem of charge structure of thundercloud we use new key evidence –the fluxes of particles from thundercloud, the so-called Thunderstorm Ground Enhancements –TGEs. TGEs originate from electron acceleration and multiplication processes in the strong electric fields in the thundercloud, and the intensity and energy spectra of electrons and gamma rays as observed on the Earth's surface are directly connected with the intracloud electric field. Discovery of Long Lasing Low energy TGEs pose new challenges for revealing structures in the thundercloud responsible for hours-extending gamma–ray fluxes. The atmospheric electric fields prolonged for many hours can influence the parameters of primary cosmic rays acquired Extensive air showers (EAS) and amount of Cherenkov light measured by large surface detectors and telescopes. In the presented report, we demonstrate that experimentally measured intensities and energy spectra of the "thundercloud"particles give clues for understanding charge structures embedded in the thundercloud. Rather short and intensive "runaway"process above detector site, which is consistent with tripole structure of the cloud electrification, is changing to much less energetic emission extended for hours. Measurements of particle fluxes and electric fields are supported by the simulation experiments with CORSIKA and GEANT4 codes.

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Atmospheric Monitoring for UHECR Space-based Missions

Author: Simon Mackovjak[1]

Co-author: Anna Anzalone [2]

[1] *Department of Space Physics, Institute of Experimental Physics, Slovak Academy of Sciences*

[2] *Istituto di Astrofisica Spaziale e Fisica Cosmica, INAF*

Corresponding Author: simon.mackovjak@gmail.com

The JEM-EUSO (Joint Experiment Missions for Extreme Universe Space Observatory) program has the ambition to observe Extensive Air Showers (EAS) induced by Ultra High Energy Cosmic Rays (UHECR) from the Space. For this purpose, the study of the night Earth's atmosphere with respect to the EAS detection is obligatory. A such study needs to address the estimation of the future main instrument performance in various atmospheric conditions as well as the development of the space-based system for direct atmospheric monitoring. The preparation of the methods for the data analysis and their fusion is also a topic that needs to be addressed. The conjuncted operation of LIDAR, Airglow Monitor, Infrared Cloud Camera and Global Light System of ground-based laser stations would provide complex information of the atmospheric conditions from the top of the atmosphere to the ground. The systems for atmospheric monitoring employed in JEM-EUSO pathfinder missions are presented and the consequences of atmospheric changes for the main instrument operation are discussed.

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Influence of cloud altitude and optical depth on CTA-N performance

Author: Sasa Micanovic[1]

Co-authors: Dario Hrupec [2]; Dijana Dominis Prester [1]; Gernot Maier [3]; Marina Manganaro [1]; Markus Gaug [4]; Tomislav Terzic [5]

[1] *University of Rijeka, Department of Physics, Croatia*

[2] *University of Osijek, Department of Physics, Croatia*

[3] *DESY, Zeuthen, Germany*

[4] *IAC*

[5] *University of RIjeka*

Corresponding Author: sasa.micanovic@phy.uniri.hr

The Northern hemisphere site of the Cherenkov Telescope Array (CTA-N) will be placed at the Observatorio del Roque de Los Muchachos (La Palma, Canary Islands, Spain) at the altitude of 2200m above the sea level. In order to obtain a global understanding of the performance of the telescopes under different atmospheric conditions above the observatory, a preliminary study has been performed. Simulations of the atmosphere calculated using MODTRAN for different cloud optical depths and altitudes have been included in the Monte Carlo simulations of the array in order to obtain the Instrument Response Functions (IRFs). CTA-N performance parameters such as sensitivity, angular and energy resolution, and their dependence on different cloud and atmospheric conditions will be shown.

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Optimization of the lidar optical design for measurement of the aerosol extinction vertical profile.

Authors: Nicola Spinelli[1]; Xuan Wang[2]

Co-authors: Alessia Sannino [3]; Antonella Boselli [4]; Gaetano Sasso [5]

[1] *Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia (CNISM) and Dip. Fisica "E. Pancini", Università degli Studi di Napoli Federico II, Napoli, Italy*

[2] *Istituto Superconduttori, Materiali innovativi e Dispositivi (SPIN) - CNR*

[3] *CNISM - Università FedericoII di Napoli*

[4] *Istituto di Metodologie per l'Analisi Ambientale (IMAA) –CNR*

[5] *ALA Advanced Lidar Applications s.r.l., Napoli, Italy*

Corresponding Author: sannino@fisica.unina.it

A lidar for aerosol monitoring with conventional optical design can provide good quality signals from several hundred meters up to tens of kilometres above the ground, but the aerosol load is mainly contained (up to 80%) in the planetary boundary layer that can have a height of the order of hundreds of meters. Therefore, the measurement of the complete aerosol extinction profile is generally a very difficult challenge.

In this paper, we studied different optical designs of Lidar systems by using ray tracing tools. Different vertical profiles of the overlap function have been obtained for different telescopes and optical schemes, showing that a lidar with an optimized optical design is able of producing signals starting from a few tens of meters above the ground. The overlap profiles obtained by ray tracing simulation and the one from an optimized lidar were also compared and verified.

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Development of a High Spectral Resolution Lidar for day-time measurements of aerosol extinction.

Author: Xuan Wuang[1]

Co-authors: Alberto Porzio [1]; Alessia Sannino [2]; Antonella Boselli [3]; Nicola Spinelli [4]; Song Chang Bo [5]

[1] *Istituto Superconduttori, Materiali innovativi e Dispositivi (SPIN) - CNR*

[2] *CNISM - Università FedericoII di Napoli*

[3] *Istituto di Metodologie per l'Analisi Ambientale (IMAA) –CNR*

[4] *Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia (CNISM) and Dip. Fisica "E. Pancini", Università degli Studi di Napoli Federico II, Napoli, Italy*

[5] *Beijing Research Institute of Telemetry (BRIT), Beijing, PRC*

Corresponding Author: sannino@fisica.unina.it

Lidar technique is the most performing way to obtain the atmosphere vertical profile of aerosol optical properties with high space-time resolution. With conventional lidars, the retrieval of aerosol optical properties (as the extinction profile) is realizable only with assumptions on aerosol extinction-to-backscatter ratio or with Raman measurement achievable in night-time.
In order to overcome this problem, the High Spectral Resolution Lidar (HSRL) technique has been examined.

In this paper we present an innovative prototype of High Spectral Resolution Lidar realized at Physics Department of University "Federico II"of Naples for the LISA (LIdar for Space study of the Atmosphere) project in the framework of the China-Italy international cooperation between CNISM and BRIT. The prototype which represents a first step of a spaceborne HSRL, is based on a laser source at 1064nm and 532nm with high spectral resolution ability at 532nm. The separation between the molecular and the aerosol components was obtained through the use of a Fabry-Perot resonant confocal cavity.