Present Activities and further Development for Space Weather and Astroparticle Studies at BEO Moussala

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Abstract— **In this work are presented several activities at Basic Environmental Observatory Moussala connected with the cosmic ray studies. The recent results of the secondary cosmic ray measurements with atmospheric Cherenkov light telescope are presented and the potential to study cosmic ray environment connection is discussed. The neutron flux meter based on SNM-15 detectors is shown and several experimental results and simulation connected with the neutron measurements are presented. The developed muon telescope based on water Cherenkov detectors is shown. The muon hodoscope is presented, precisely several estimations and the possible design. The scientific potential, precisely the potential for space weather and atmospheric transparency was discussed. The further development for astroparticle studies is presented.**

I. Introduction

The high mountain observatories are privileged places taking into account the unique characteristics. They have been exploited during the years not only for cosmic ray but also for environmental studies. Generally the following specific objectives are pursued in attempt to provide basic information permitting analysis of the connection between cosmic ray variation and atmospheric parameters. The aim is the detailed, precise and contemporary measurements of cosmic ray intensity especially the muon, electron, gamma and neutron component and last but not least the atmospheric Cherenkov light. At the same time the atmosphere parameters, including anthropogenic products as well in different conditions of altitude, latitude and urban development is needed.

The connection between low energy cosmic ray and the Earth atmosphere is obvious. At the same time it is a good basis for study of solar-terrestrial influences and space weather [1]. Moreover the ability to forecast for long term space weather needs a precise knowledge of solar activity. The space weather refers to conditions on the sun, solar wind and Earth's magnetosphere and ionosphere [2]. Several characteristic signatures in cosmic ray may be used for space weather applications [3] on the basis of neutron monitor data. Good examples are the solar proton events and Geomagnetic storms.

One of the significant points is related with the atmospheric transparency and cloud formation. The variations of the cosmic rays solar and galactic may be responsible for the changes in the large-scale atmospheric circulation. It is possible to associate such type of phenomena with solar activity and precisely within the energy of cosmic particles being 0.1–1 GeV [4], [5]. It is obvious that possible mechanism of cosmic ray effects on the lower atmosphere involves changes in the atmospheric transparency which is connected with cloud cover. This is possibly due to the changes in the stratospheric ionization produced by the considered cosmic particles. Moreover cosmic ray reflects on the atmospheric temperature assuming mechanisms related with cloud formation that may be associated with the changes in the ionization of the stratosphere during the solar cosmic ray bursts [6].

Thus the transparency is one of the primary measures of the atmospheric state. It is obvious that long term series of atmospheric transparency measurements gives the possibility for quantitative estimate of the variability of air and therefore to make climatologic conclusions with regard to contamination, cloud formation, humidity and radiative exchange.

Taking into account the mentioned above motivation we present in this paper several activities at Basic Environmental Observatory BEO Moussala connected with both space weather studies and astroparticle research.

II. Present Activities

One of the main activities performed at BEO Moussala is connected with secondary cosmic ray measurements precisely neutron and muon component. The secondary cosmic ray neutrons are produced by interaction of primary protons or other nuclei with atmosphere nuclei, and the neutron production rate and energy distribution strongly depend on the atmosphere physical characteristics such as the chemical

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composition, humidity, cloud density. Additionally the secondary cosmic ray neutrons give an important contribution to the total dose in human exposure to cosmic radiation environment. Actually the obtained dose rate from secondary cosmic neutrons is the most important part of the dose produced by cosmic radiation. With this in main a neutron flux meter is developed at BEO Moussala.

According the initial design [7] the neutron flux meter is based on gas detectors type SNM-15 filled with BF_3 enriched to 90% with B^{10}. The detectors are situated under the roof of the main building of BEO Moussala. The complex is divided in two modules each one of 3 detectors. As example in Fig.1 is shown module of two detectors including the tanks containing moderator. This detector configuration is without lead i.e. is only with neutron moderator. This is the main difference comparing to the usual neutron monitors. The principle aim of the presented device is the measurement of the absolute neutron flux of secondary cosmic ray radiation. It is clear that the precise Monte Carlo modeling of the detector response is needed, the final aim being to estimate precisely the expected counting rate.

Fig. 1. Module of two detectors of the neutron flux meter at BEO Moussala

The results from experimental measurements of neutron spectra at High Mountain Observatories [8] are used for modeling of the source of secondary cosmic ray neutrons and therefore to estimate the response of the neutron flux meter at BEO Moussala. The aim is to estimate the moderator layer and to estimate the expected counting rate as a total neutron current. The results of simulations with MCNP code permitted to choose the moderator layer to 12.5 cm of polyetilen which was the initial design.

The final design is with glycerin moderator with the same thickness. In this connection the total cross section for neutrons having different energies with polyetilen and glycerin are compared. The cross section for elastic processes in the energy range of interest is in practice the same shape and the difference is less then 5%. The detailed presentation of the detector complex is shown in the proceeding if the same conference.

Another device is the developed muon telescope. The aim is

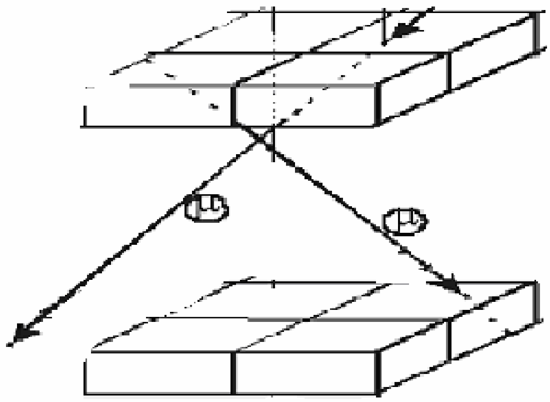

Fig. 2. Muon telescope based on water Cherenkov detectors

the registration of secondary muons and measuring the cosmic rays variations. The original design of the telescope is based on 8 water Cherenkov detectors which are split in 2 slabs of 2x2 cells. The dimensions of the tanks are 50x50x12cm. The penetrating muons create Cherenkov photons registered by photomultipliers Fig. 2. The telescope is under absorber so the electrons are rejected. The distance between the two identical modules is 1m.

The muon telescope is complementary to neutron flux meter. Using both devices it is possible to study with different methods and techniques the variations of cosmic ray. Moreover taking into account the present monitoring activities at BEO Moussala especially connected with atmospheric investigations obviously it is possible to find out correlation between cosmic ray variations and some atmospheric parameters. It is clear that such possible connection may be used only as a local reference point in a global model.

As was mentioned above it exist possible connection between cosmic ray and atmospheric parameters. On the other hand the transparency is one of the primary measures of the atmospheric state and thus very important signature.

In this connection is very important to provide additional measurements of the integral atmospheric transparency. Thus we study the possibility to estimate the atmospheric transparency using Cherenkov light from extensive air showers measurements. Moreover such type of measurements gives excellent possibility to investigate different atmospheric profiles. Generally the atmospheric density profiles as well as several light absorption and scattering processes depend on geographic position. Moreover they are time-variable. Obviously different density profiles lead to differences in Cherenkov light density of up several tenth percents. Seasonal variations at mid-latitude sites are of the order of 15–20%. Such type of study is possible to perform using atmospheric Cherenkov light telescope.

The detector represents two parabolic mirrors with 1.5 m diameter and focal length of 1m presented in Fig.3. The detector design is the same as the Ice Lake experiment at BEO Moussala, but in this case is used for zenith measurements. The preliminary studies precisely Monte Carlo simulations with CORSIKA 6.3 code [9] using GHEISHA [10] and QGSJET [11] hadronic interaction models are carried out for transparent (without any absorption) atmosphere. Similar simulations are performed for atmosphere with Mie and Rayleigh scattering. The simulations are carried out for Alomar observatory observation level i.e. sea level and Moussala observation level of 2925 m above sea level. The results of these simulations for Moussala observation level are presented in Fig. 4.

Fig. 3. Atmospheric Cherenkov light telescope based on two parabolic mirrors.

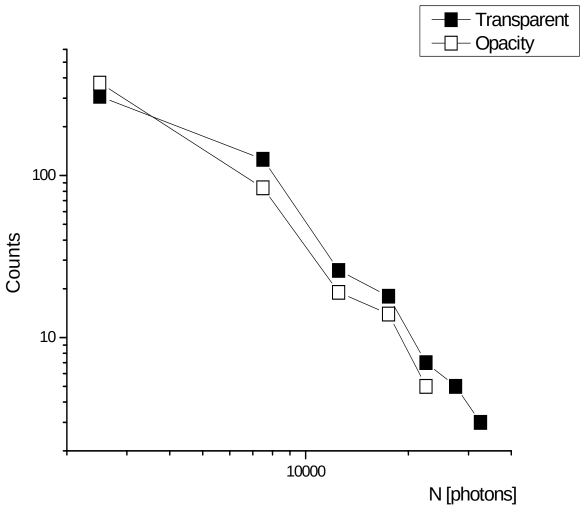

Fig. 4. Simulated with Corsika 6.3 code amplitude Cherenkov spectra using different atmospheric profiles.

During the simulations are used different atmospheric profiles [12] and algorithms in Corsika 6.003 code for simulation of Mie and Rayleigh scattering. The simulated events are 5000 and are randomly distributed at 300m from the detector. The simulated showers are initiated by primary protons in the energy range between 10^{13}-10^{17} eV. One observes the similar shape of the obtained amplitude spectra. The obtained slopes of the spectra are in practice the same. An additional analysis of the detector response as a function of energy threshold and effective area is necessary. At the same the telescope is used for estimation of the primary cosmic ray spectrum around the “knee” on the basis of the reflected by snow surface atmospheric Cherenkov light.

III. Further Developement

The further development of BEO Moussala is connected more or less with the mentioned above devices and studies. The first activity is connected with the detailed Monte Carlo simulation of the detector response of the neutron flux meter, precisely the influence of neighbor objects, snow layer at the rough of the station etc…Moreover on the basis of Monte Carlo technique it is possible to build a reconstruction model for data analysis of the measured events and afterwards to estimate the obtained dose rate.

One of the further projects is connected with atmospheric transparency studies. A possible method yet in development is based on the well known astro-photometric method i.e using stellar standards and star light. Generally in optical astronomy an effect which must be corrected when calibrating instrumental magnitudes is the atmospheric extinction or the dimming of starlight by the terrestrial atmosphere. The longer the path length the starlight traverses through the atmosphere the more it is dimmed. Thus, a star close to the horizon will be dimmed more than one close to the zenith, and the observed brightness of a given star will change throughout a night, as its zenith distance varies. The path length through the atmosphere is the air mass. Different assumptions can be used for computation of the air mass. A good approximation is given in [13]. The atmospheric extinction coefficient can be determined by observing the same object (through an appropriate filter) at several times during the night at varying zenith angles.

When the observed magnitudes of the object are plotted against computed air mass they should lie on a straight line with a slope equal to extinction coefficient $k(\lambda)$. It is important to note that the extinction is dependent upon wavelength, being greater for blue light than red. Moreover the use of different filters (as example the standard UBV system with extended IR filters) can provide additional

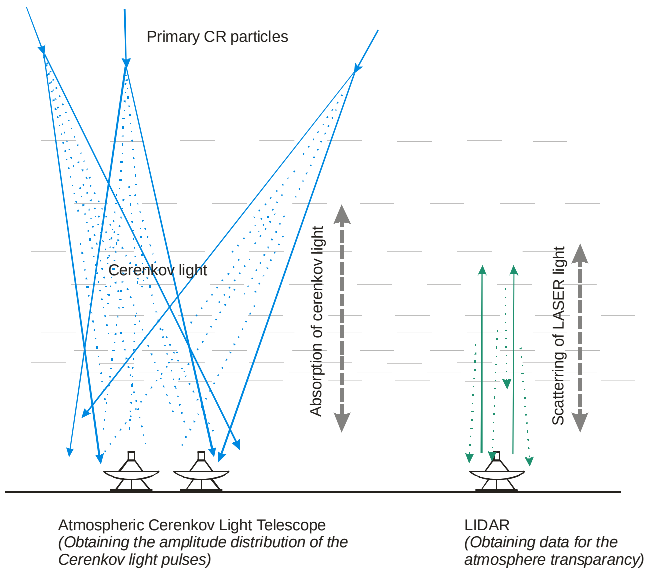

Fig. 5. Simultaneous measurements of atmospheric transparency with Cherenkov light telescope and LIDAR.

information about the atmosphere state. A telescope of about 20 cm mirror equipped with the CCD camera and corresponding filters will be necessary for estimation of the extinction of BEO Moussala. Presently a 10cm diameter with focal length of 500mm camera is constructed and tested which will be used for the first measurements.

Additional measurement with LIDAR or sun photometer can give important information concerning the aerosol abundances in the atmosphere. This permits to estimate the different contributions leading to light absorption. One of the most important aims is to estimate the aerosol contribution at high mountain observation level. Generally two kinds of scattering are important: scattering by molecules of air, and scattering by solid particles or liquid droplets suspended in the air. Molecular scattering is usually called Rayleigh scattering. The suspended particles, on the other hand, are collectively known as aerosols, and their contribution is called aerosol scattering. Atmospheric aerosols are very diverse. They include tiny grains of mineral dust stirred up from the ground; particles of salt left when droplets of sea spray evaporate; bacteria, pollen grains, mold spores, and other “biosol” particles; photo-chemically produced droplets of sulfuric acid and other pollutants; soot particles produced in fires, and in vehicle exhaust; and many other materials. As most of these are produced at or near ground level, and are washed out of the atmosphere by condensation of cloud droplets on them, followed by precipitation, the aerosols all tend to be concentrated in the lowest part of the atmosphere; an exponential distribution with a scale height of about 1.5 km is a rough approximation to their vertical distribution. Because of their diversity, aerosol particles have a wide range of sizes. However, the ones most important for optical scattering turn out to be comparable to the wavelength being scattered, for typical size distributions.

Most of the aerosol particles are so weakly absorbing that their extinction is almost entirely due to scattering, rather than absorption. However, soot (carbon) particles are quite strong absorbers, and a considerable part of their reddening is due to the increase in their absorption at short wavelengths. Absorption by molecules is sometimes called “true absorption,” to emphasize its difference from extinction due to scattering; or “selective absorption,” to emphasize its concentration in narrow spectral bands. The main absorbers in the visible spectrum are ozone (which absorbs in the Chappuis bands, in the orange part of the spectrum), water vapor (several bands in the longer-wavelength regions, noticed mainly under very humid conditions — hence the name “rain bands”), and oxygen (which produces Fraunhofer's A and B bands). Of these, the Chappuis bands of ozone are probably most important in green flashes, as they absorb strongly just in the wavelengths between red and green, and probably contribute to the abruptness of the color change seen in green flashes. The water-vapor bands are usually much less important. Thus it is easy to see the proposition at BEO Moussala to provide atmospheric transparency measurement

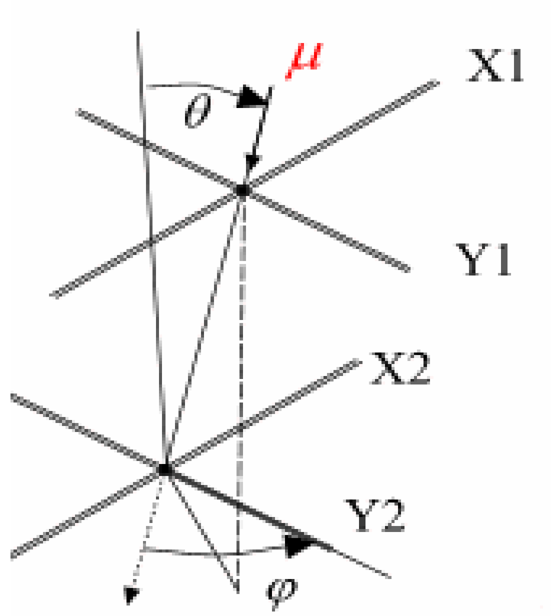

Fig. 6. Angles with detection principle of muon hodoscope .

with three different methods i.e. photometric standard using starlight, Cherenkov radiation and tropospheric LIDAR. At the same time within the aerosol measurements this will give excellent possibility to estimate the different contributions on the total atmospheric transparency. After that is a question of model predictions to estimate their impact on the environment and the connection with cosmic ray variations. Simultaneous measurements with atmospheric Cherenkov light telescope and LIDAR in under development see Fig. 5. Several preliminary studies was carried out at Alomar observatory.

For real time researches of solar-terrestrial relations it is required to register simultaneously as more as possible of phenomena in heliosphere. For this purpose, it may be very useful to use ground-based muon hodoscope with high angular resolution that detects muons of cosmic rays with energy around 10GeV. Solar flares, scattering of protons by interplanetary shock waves, fluctuations of the air density distribution in the atmosphere will change ground level muon intensity. Amplitude of such variations can reach maximal value in various energy-active regions of the Earth near magnetic poles, tropics, sea coast of continents etc.

The muon hodoscope represents multi-channel device generally based on plastic scintillators. The original design of the hodoscope [14] is 512-channel large aperture muon hodoscope the aim being the investigation of solar-terrestrial physics. The estimated threshold of primary cosmic ray is 10 GeV. The estimated accuracy of measurement of cosmic ray muon directions is about 1-2 degree. The area of the hodoscope is $9m^2$ and its counting rate is about a thousand events per second. The principle is shown in Fig. 6.

The muon hodoscope is made of four layers. Each of the layers consists of 128 counters with a 2 mm iron sheet in front to reduce of the amount of knock-on electrons. The distance between the two pairs of layers is about 1 meter. To reject the soft component, the 5 cm thick lead filter is used. The scientific potential of the muon hodoscope is enormous. Starting from internal gravitational waves, measurement of the temperature field along height of the atmosphere, registration of acoustic waves [15] etc… In the presented design instead scintillator detectors we will use water Cherenkov detectors. One possible design of the detector is a cylinder with 10 cm diameter and one photomultiplier. The registration efficiency of the proposed water Cherenkov is estimated using modified version [16] of EGS4 code [17]. The estimated registration efficiency is 91% assuming 5 GeV energy muons. The detailed description of the muon hodoscope project is presented in this proceedings.

IV. Conclusion

In this work are presented several at BEO Moussala activities connected with secondary cosmic ray registration, especially the neutron, muon and Cherenkov component. The neutron flux-meter is presented within some estimation concerning the final design. The muon telescope based on water Cherenkov detectors is shown. The atmospheric transparency present activities and further project are discussed as well several results concerning the expected amplitude spectra. The muon hodoscope project is mentioned.

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