A system of medium resolution for monitoring the night sky background in the visible and near UV range

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Abstract: In this work we focus on a design of a medium resolution spectrograph for the night sky background radiation, in conjunction with appropriate telescopes, in order to seek for the optimum performance. Best results seem to be obtained using concave gratings. Using a grating with about 800 grooves per mm designed for flat field spectrograph and 24 cm focal length, we are able to record night sky background spectra in a reasonably small time interval while the light detector used is based on a commercial dSLR camera. The spectra obtained show the expected line from atomic oxygen nightglow at 557.7 nm, and the pseudo-continuum part is consistent with data from telescope-based spectrometers. This instrumentation may become a versatile tool for diagnostics in Extensive Air Shower fluorescence telescopes development and operation.

1. Introduction

The objective of measuring the Ultra High Energy Cosmic Rays spectrum, using the Extensive Air Shower (EAS) fluorescence techniques or air Cherenkov telescopes, can be achieved only if the signal to noise ratio in the recorded data is maximized, and also if the optical noise spectral structure and short and long term variations are well understood. Although, in some EAS fluorescence telescope systems, significant work has been and is being conducted in order to study and quantify the night sky background [1], we proceeded to the design and implementation of a dedicated, portable and low-cost, spectroscopic facility in order to develop a diagnostics and optical noise experimental tool, useful for the statistical analysis of the signal and noise. The ultimate goal of this project is the reliable quantification of the error in the energy and chemical composition determination of the Ultra High Energy Cosmic Rays (UHECRs). Many studies have concentrated on the study of Night Sky Background Radiation (NSB), using instrumentation on balloon [2] or satellite based platforms [3], and in ground based telescopes [4]. We have selected a low-cost, ground based instrumentation approach using existing technology in order to produce a more flexible apparatus that can be adapted by present and planned observatories of UHECRs. One should stress that the space based EAS detectors, where the multi-alkali photocathodes have been proposed, have spectral sensitivity up to 800 nm [5]. Therefore, we worked on available components and converted them for the purpose presented here. This is sensitive in the spectral range 360-780 nm, where the photomultiplier detectors typically used in EAS fluorescence installations are sensitive. The use of optical filters do not achieve the full protection from the visible background since even the absorption filters have a small but finite transmittance in the red part of the visible range. In next section, we present the design principles of the spectrometer, and results for the spectral and intensity calibration of the spectrometer, while in section 3, we give preliminary results on the measurements of night sky backgrounds in various locations in Greece. Finally in Section 4, we report the conclusions and prospects for the future work.

2. Design principles and specifications for the night sky spectrometer.

This relative simple and low-cost spectrometer uses a holographic concave grating with reciprocal linear dispersion (RLD) about 4.5 nm/mm to analyze the incident light and a dSLR camera with quite large CCD sensor as a detector. According to camera's specifications CCD size is 23.7 mm x 15.6 mm, while the pixel size is about 7.8 μm x 7.8 μm. Using the maximum width of the camera we are able to cover the whole visible region in only three frames. The software for handling of the information of the pixels matrix is IRIS and Visual Spec. Generally, The wavelength resolution is limited mainly by the f/number of the telescope. However, in the present results we record data without a telescope, and therefore, the wavelength resolution is mainly affected by the f/number of the grating. The geometrical parameters of the grating along with a comparative scheme of CCD size are presented in Figure 1, where a is the incident angle, b_1 and b_2 the diffraction angles for the 1st and 2nd order measured from the grating's normal. The design is compatible with flat field spectrographs, i.e. with CCD cameras.

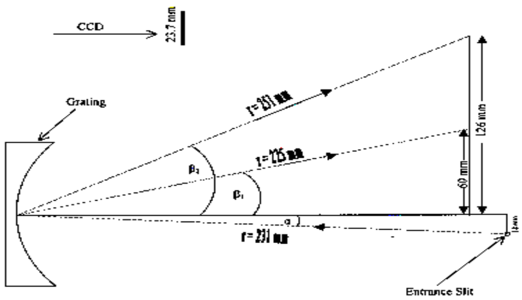

Figure 1: The direction of light with wavelength 380 nm for the 1st and 2nd order.

2.1 Spectral calibration

The calibration of the Spectrograph is conducted with a Pt-Ne hollow cathode and an Hg lamp as can be seen in Figures 2, 3 and 4, 5 respectively.

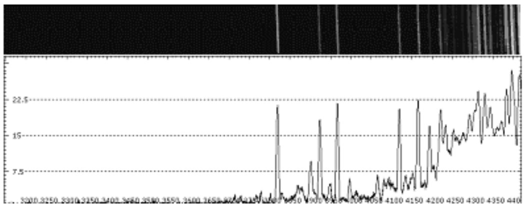

Figure 2: Pt-Ne spectrum, 320-440 nm.

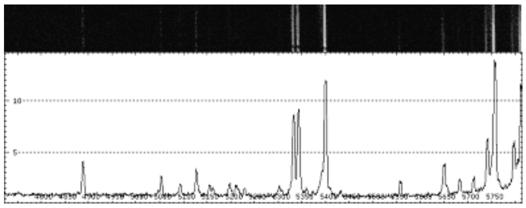

Figure 3: Pt-Ne spectrum, 475-580 nm.

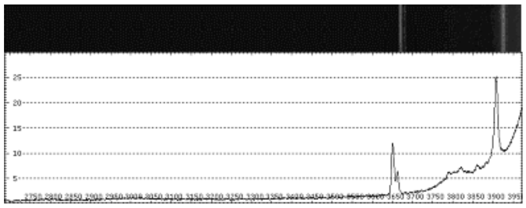

Figure 4: Hg spectrum, 275-395 nm.

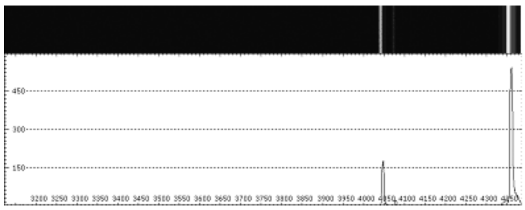

Figure 5: Hg spectrum, 315-440 nm.

For line identification of all the above spectra we used data from [6]. With a 100 μm entrance slit resolution of 0.5 nm is easily achievable as can be seen in the above figures. Also from Figures 2 and 4, one can observe that setup's efficiency is satisfactory for wavelengths down to 365 nm and then falls rapidly for lower wavelengths.

2.2 Intensity calibration:

A difficult task is how to estimate the intensity calibration in each spectral interval. For this purpose, we are recording spectra of the diffuse daylight as these assumed to be accurately known from literature for each location, time of the day, day of the year and viewing orientation. Such a spectrum is seen in Figure 6.

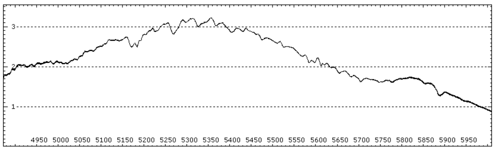

Figure 6: Solar spectrum recorded in a time interval of 5 s.

We clearly observe the well-known Fraunhofer lines suggesting the sensitivity of the spectrometer. An additional intensity calibration is to record direct moon spectrum. This can be easily achieved with a collimator in front of the slit. A typical full moon spectrum in the range 420-540 nm taken outside the NTUA Physics Department building is seen in Figure 7.

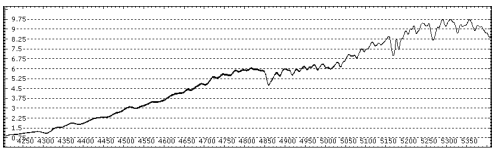

Figure 7: moon spectrum recorded in a time interval of 410 s.

3. Night sky measurements

A primary investigation of how Athens' artificial light affects night sky measurements has been done. The results we obtained from mountains Penteli (15 km), Kithairon (40 km) and Dirfys (70 km) clearly show that Athens is a very high light-polluted site. Hence, a measurement of night sky background in a remote location more than 100 km away from Athens' center is required in order to observe peaks due to atmospheric emissions in UV region. Other environmental parameters including moisture etc may also be considered. In Figures 8 and 9 we show the results obtained at distances 40 and 75 Km from Athens area respectively.

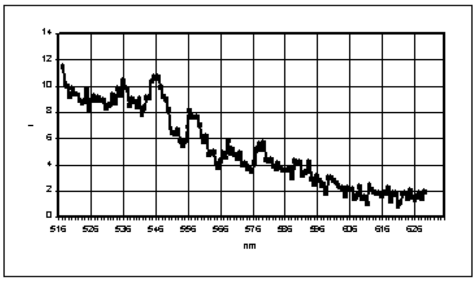

Figure 8: Night sky spectra from mountain Kithairon.

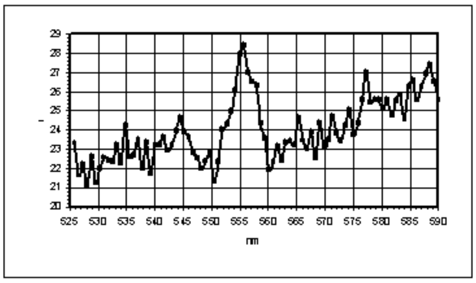

Figure 9: Night sky spectra from mountain Dirfys.

The curve in Figure 8 indicates the presence of moonlight. Indeed the data taken corresponded to the 4^{th} day from new moon. Also, lines that may be ascribed to artificial illumination are present, mainly from mercury and high-pressure sodium street lamps. In contrast, the same artificial lines are much weaker in the spectrum presented in Figure 9, which is dominated by the OI line at 557.7 nm. The resolution of the spectrometer without a collimator is around 5 nm. The time used to record most of the spectra was around 30 min. This time period may not be necessary if we combine the spectrometer with a telescope.

4. Conclusions and prospects

Although the night sky measurements we previously discussed are in visible region, these preliminary results show that such a spectrograph is capable for recording night sky background if we do a few modifications in the current setup. Lab tests also support this fact. In the next paragraph we discuss some improvements of the present setup.

Firstly, coupling the existing spectrometer with a f/15 Meade Maksutov-Cassegrain telescope of 127 mm aperture in order to achieve higher resolution and better throughput has been scheduled and is shown in Figure 10. A liquid light guide with 5 mm core diameter will make the coupling. Liquid light guides combine high transmission in UV region with large input area and thus they are the most suitable coupling components for our purpose. Furthermore, the substitution of the present grating with one of better efficiency in UV region and the purchase of a more UV-sensitive camera with additional cooling for dark noise reduction has already planned.

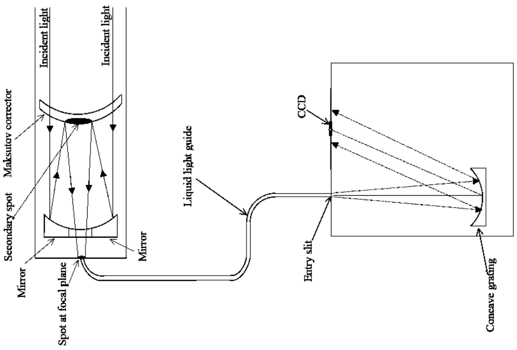

Figure 10: Spectrometer coupled with telescope via a liquid light guide.

In conclusion, we present a low-cost, portable instrument with capability to provide the night sky background in ground based EAS telescope locations. In particular, it can provide the NSB dependence on zenith angle and with further automation, it could give the NSB during night-time at intervals around 15 min. In a future improvement, we plan to be able to record a wider spectrum of night sky background covering the range 300 to 850 nm, which covers the range of sensitivity bi-alkaly and multi-alkali phototubes. We are planning to insert the collected data in a database, which will be accessible to researchers, developing simulation Codes for EAS phenomena such as CORSIKA, so that spectrally meaningful estimators of night sky background can be developed.

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