Review of High Spectral Resolution Techniques for Measurements of the Aerosol Phase Function and Application in Extensive Air Shower Detector Atmospheric Monitoring

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***Abstract*. We describe at first a review of the techniques used in the area of High Spectral Resolution Lidars (HSRL) for studying the aerosol phase function. We present for the first time results from the application of this technique in Extensive Air Showers telescopes atmospheric monitoring systems. We present our progress towards assembling such instrumentation. Using this, we are aiming to investigate the aerosol optical properties in the lower troposphere measuring the scattering cross section as a function of height.**

***Keywords*: Atmospheric monitoring, HSRL, EAS**

I. INTRODUCTION

The atmospheric monitoring forms what is known as remote sensing of atmospheric properties with emphasis in Air Fluorescence or air Cherenkov Extensive air showers telescopes. In the experiments for Ultra High Energy Cosmic Rays the signal that fluorescence detectors collect must be corrected with the proportion to the instant atmospheric conditions, mostly due to the aerosol component. While the general atmospheric monitoring is presented in many references as for example in [1], the issue of aerosol phase function measurement is usually treated by using as a detector the fluorescence telescopes themselves as for instance is presented in [2].

Different geometries have been proposed for LIDAR atmospheric monitoring. The most popular is the one that the emitter and the receiver are in backscatter mode. This means that light is collected only at the angle of $180\ ^0$ as measured from the emitter. The light source is usually a pulsed Laser, so that the time interval determines the distance from the system. The backscattered light is usually collected by a mirror, filters reject the background light and finally photomultipliers, record the total amount of signal. In this way, a number of channels can be developed at a Lidar system, with different filters, measuring deferent atmospheric parameters, such as elastic scattering, Raman scattering etc. More sophisticated systems, like High Spectral Resolution Lidar (HSRL) use spectroscopic or inteferometric or other techniques in order to determine the exact components of the scattered light for high accuracy measurements.

At such EAS experiments, for determining the aerosol phase function, typically a laser or some pulsed xenon lamp, emits light and the fluorescence detectors receive the light scattered. This light contains mainly two components. The one is due to Mie scattering from aerosols and the other is the Rayleigh scattering due to molecules. In order to distinguish these two components the Rayleigh night has to be used for the rejection of the signal due to molecules. The Rayleigh night is a night with out aerosols. This method is based on the fact that the Rayleigh component has the same value for every other night. This assumption can be avoided if the Rayleigh component can be determined at the moment of the measurement.

We present, therefore, another alternative approach, namely the use of dedicated detector in bi-static interferometric LIDAR. The most recent progress in the technology of HSRL is presented in [3]

Recent efforts consider use of Fizeau type interferometer due to its simplicity and lower cost as compared to Fabry-Perot.

In addition, the Fizeau type interferometer analysis has been given in detail in [4] where the shape of the MFW (Multibeam Fizeau Wedge) fringes are quantified according to [5]. The resulting advantages of these techniques include, first, a better adaptation of interference fringe pattern to an orthogonal shape ccd, and, secondly, that the pattern can be detected simply by placing the detector at the exit of the wedge. The limiting resolution can be around one part to a million in wavelength in the center of the visible region. Several other factors can influence the final choice of a Fabry-Perot or a Fizeau type is going to be made after careful consideration.

II. Progress of HSRL Prototype

On the progress for the assembly of the aerosol phase function measuring we present the technique of bi-static High Spectral Resolution LIDAR, which has not been up to now successfully implemented for atmospheric monitoring in EAS Fluorescence Telescopes. To this aim, we have constructed a prototype receiver based on a (D = 25.4 cm) Newtonian telescope and the two channels Fabry - Perot etalons. The light radiation at the exit of this telescope is reflected by a beam splitter (20 % reflectance) and is directed to the molecular channel. The remaining transmitted signal enters simultaneously to the aerosol channel. The receiver system will be based on a Fabry - Perot (FP) etalon with a 50mm spacer and a liquid nitrogen cooled CCD, while the molecular channel will use FP etalon with 2.5 or 5mm spacers, and a thermoelectrically cooled CCD. The corresponding emitter is a Single Longitudinal Mode 532nm DPSS continuous wave laser at about 100m distance from the receiver place. Both parts of this system will stand on robust bases to avoid mechanical vibration effects in the interferometer operations as well as on the laser oscillator. We intent to measure not only the aerosol distribution, we are going also to investigate the functionality of the system. We present details on the specifications of a Liquid Nitrogen Cooled CCD camera used for recording the interference pattern of the aerosol channel. The combined performance of this detector with the strength of the arriving signal to the telescope will determine the sensitivity of our bi-static LIDAR system. We give first results on the operation of the LIDAR with the DPSS CW laser at 532 nm, and make estimations for this sensitivity as a function of atmospheric height.

A. HSRL Emitter

1. It is based on a NdYVO4 laser at 1064 nm with a KTP frequency doubling crystal. The effort for characterization of the laser at 532 nm , at the steady state conditions, has shown that its frequency stability has some short term and long term performance which is difficult to be quantified with the Fabry-Perot interferometers used for this purpose. More details about the laser frequency stability are given in a following section.

B. HSRL Receiver

The aerosol channel has been modified to use a liquid nitrogen cooled ccd in order to increase the signal to noise ratio.

The molecular channel is using a thermoelectrically cooled ccd.

Use appropriate optics on the receiver to allow the incoming scattered radiation to be transmitted through the two channels via the beamsplitter.

Introduction of narrowband optical filter at 532 nm in order to effectively reject the night sky background.

Some very preliminary results of the operation of the CCD at Liquid nitrogen temperature are seen below:

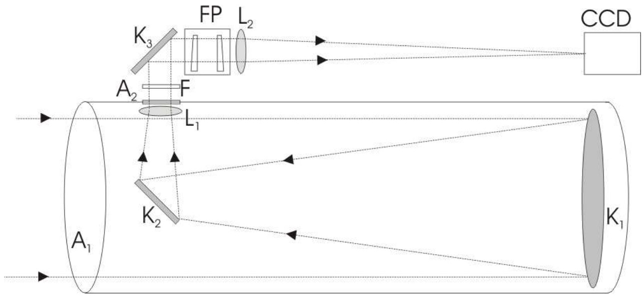

Fig. 1: Ray tracing in the Newtonian telescope with one of the two Fabry-Perot channels visible in this Figure.A1, A2: telescope apertures, K1, K2, K3: Mirrors, primary, secondary and another diagonal, L1, L2: Lenses, F: interference filter, FP: Fabry-Perot Interferometer

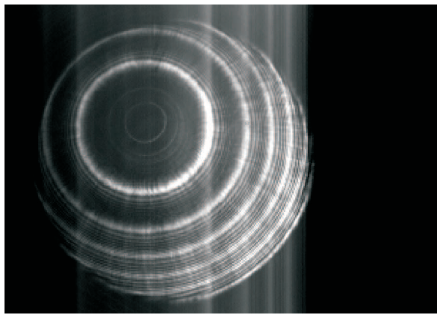

Fig. 2: A very preliminary Fabry-Perot fringe pattern using the E2V 30-11 ccd cooled at -130^{0}C.

More details about the noise performance of this ccd sensor are given later in appropriate section.

C. Testing plan for the Molecular Channel using the 557.7 nm mesospheric line

One of the preliminary tests forseen for the Molecular Channel is to try to record the well-known auroral line of neutral atomic oxygen at 557.7 nm using narrowband optical interference filter with a passband of 1 nm. This will allow this linewidth to fit withing the free spectral range of this etalon (FSR= 1 cm^{-1}). We are using such an etalon made by QueensGate Instruments, based on aluminum mirrors.

III. Laser frequency stabilization and characterization

Due to the competition of the longitudinal modes, the interference fringe patterns contain not only the main mode but some lower intensity fringe patterns due to other allowed modes (mode hopping).he design longitudinal mode spacing is 4.5 Ghz although this can vary slightly between systems and is calculated according to the Fabry-Perot Etalon formula.

Since the system is thermally stabilized, minimizing temperature fluctuations in and around the laser head and driver would help to minimize any instability. We are considering such improvement in the future. We are considering to enclose the laser cavity in a temperature controlled environment. Therefore, we study some of the methods used to allow the laser radiation to achieve the necessary monochromaticity and to characterize their frequency stability. More specifically, we use for the laser characterization either a commercial Optical Spectrum Analyzer or Fabry - Perot etalon systems with various Free Spectral Ranges (FSR).

We study the design of frequency stabilization of a commercial Single Longitudinal Mode (SLM) continuous wave laser at 532nm using an external 10cm long Fabry - Perot cavity immune from mechanical and acoustical vibrations in a temperature controlled environment.The immediate work plan is to apply relevant design in Superinvar cylinder as the basic structural element of such optical reference cavity. Our aim is to achieve better stability than 0.01cm^{-1} in the optical reference cavity. We explore the possibility to use such a laser to create an injection seeded Nd:YAG or Nd:VO4 pulsed laser which approaches the Fourier transform limited performance.

IV. Improving the CCD noise using Liquid Nitrogen cooled CCD

The sensitivity of the HSRL is discussed in [6].
The insertion of the narrowband optical filter is going to improve the signal to noise ratio considerably. This has been discussed in [7].
We also consider to utilize the polarization state of the laser so that the contribution of the unpolarized night sky background is minimized. The relevant technique, utilizing a polarizing beam splitter and a 1/4 Wave plate is described in [8] Most of all, when operating the HSRL using as laser the emitter in CW mode, it is critical to use a low temperature ccd to improve the signal to noise ratio. This would improve significantly the S/N ratio in recording the Fabry-Perot interference fringes. The relevant performance cannot be evaluated correctly from the Figure 2 interferograms as it may include some light leak during the measurements as well as inaccurate alignment or mechanical vibration effects during the data taking. For this reason we analyzed runs with the camera closed so that we can evaluate the overall noise as a function of temperature. The results are seen in Figure 3. The E2V based ccd was assembled in a dewar having fused silica window by XCAM Ltd , who provided the ccd camera controller [9]

For the duration of the data, the noise is dominated by the read-noise which is evaluated first according to our experimental values as well as computations according to the manufacturer data sheets. We plan to make further measurements to extend the exposure times to more than a few minutes. In this way, the signal to noise ratio will be significantly improved.

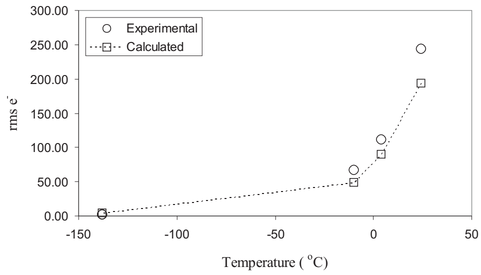

Fig. 3: The total noise of the E2V ccd as a function of temperature , (a) experimental and (b) calculated

V. Conclusions and Prospects

We are preparing for systematic measurements to characterize the performance of the E2V ccd sensor at -130^{0}C with regard the read-noise, and dark count as well as to compare its performance with other available ccd camera operating with thermoelectric cooling. We are in the process of analyzing preliminary interferograms using the E2V camera at liquid nitrogen temperatures and also prepare to take such data under single longitudinal mode operation using low intensity laser source; the intensity of the latter will correspond to this expected from scattering by typical aerosol concentrations a various heights. In this way, we expect to determine the sensitivity of our HSRL system.

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