

# Use of the Fabry-Perot Interferometer for atmospheric and night sky background monitoring in EAS detection

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The Fabry-Perot interferometry is studied for determining the aerosol to molecular ratio for use in Fluorescence Detectors. This can be realized using an etalon with Free Spectral Range (FSR) of  $0.05 \text{ cm}^{-1}$ . Another use of this instrumentation is considered in monitoring the intensity of some typical spectral lines of the night sky background radiation in EAS detection with the fluorescence or air-Cherenkov technique. These lines are that of atomic oxygen at wavelengths 557.7 and 630.0 nm, and also that of mercury at 365 nm, caused by artificial light pollution. We present preliminary laboratory results and evaluate their capabilities to meet the requirements of the above two calibration issues of EAS measurements.

## 1. Introduction

The aims of this paper are two-fold: First, to consider an alternative approach in the atmospheric monitoring for EAS detection telescopes. Secondly, to consider applications of the instrumentation proposed in the area of measurement of the main components of the night sky background in the EAS signal. The use of Doppler Lidar for determining the aerosol to molecular ratio is described in reference [1]. In this work we try to present what possibilities exist in assembling a necessary experimental setup to do just these measurements. We also present possibilities to use Fabry-Perot interferometer (FP) [2] to obtain useful data for the EAS event analysis. The determination of atmospheric parameters can be used in both EAS Fluorescence Detectors and water Cherenkov surface detectors for correcting the data for aerosol scattering effects. The FP interferometer can allow an accurate aerosol to molecular ratio from interferometric data analysis. On the other hand, the FP in conjunction with a Doppler Lidar can give the air-temperature as a function of atmospheric height and lead in, event by event basis, useful air-temperature data necessary for accurate simulation of the EAS signal. For instance, the interferometer data can input to EAS CORSICA code as alternate set of data, instead of data of radiosondes used for temperature profiles. One may consider, before proposing the interferometer use, the advantages, in terms of performance and cost of using this method. In the following, we present the progress in the assembly of an appropriate FP etalon together with design and performance issues. In addition, depending on the level of sophistication demanding from such Doppler Lidar system, one should consider if the technique is mature enough to be used in existing experiments (Auger South) or it should be considered for a later stage (Auger North).

The method to measure the NSBR with very high sensitivity has been proposed and greatly advanced as described in reference [3]. The limitations presented in this work had to do mainly with the flatness quality control of the FP etalon used. In reference [4], the same type of measurements have recently been achieved with a smaller aperture FP etalon, and in addition, the neutral wind velocities of these Oxygen atoms can be determined with an uncertainty ranging from 8 m/s to 50 m/s for the lines 557.7 nm and 630.0 nm, respectively. In Section 2, we present a quick review of the Doppler Lidar method. In section 3, we present the elements for the design of the appropriate FP etalon for a) for the aerosol to molecular ratio determination and b) for the determination of the spectrum of NSBR. The conclusions and prospects are described in Section 4.

## 2. Doppler Lidar concept

Using a laser beam directed to the atmosphere, we can detect the scattering from each atmospheric height when the beam is interrupted by a chopper rotating at an appropriate angular velocity. We can spectrally analyze the scattering at very high resolution using a FP interferometer. The molecular components of the atmosphere give a broad spectral signature which is governed by the Maxwell-Boltzman distribution of the velocities and the effect of the Doppler broadening. The scattering cross-section for each type of atmospheric molecule is governed by the well-known elastic Rayleigh formula, while for the particulates of aerosol type, the magnitude of the cross-section is described by the Mie scattering formalism, which reminds diffraction effects and leading to much stronger scattering cross-section. Since the aerosol particles have considerable larger mass, their spectral analysis corresponds to a narrow peak on top of the broad molecular spectrum. Appropriate light sources for this purpose are described below. The obtained spectrum allows the separation of the molecular and aerosol component which is needed to evaluate the effects of the scattering of Cherenkov radiation from the aerosols.

## 3. Design of appropriate FP etalons

Concerning the design of the FP etalons and their operation and tests, we describe the three main works (stages) described briefly below:

- I. We considered etalons with FSR of  $0.25 \text{ cm}^{-1}$  and  $0.5 \text{ cm}^{-1}$  which are sufficient for the purpose mentioned above. The mirror flatnesses of both interferometers used, is between  $\lambda/150$  and  $\lambda/200$ . We give the characteristics of the etalons and how they are obtained by photographic images.
- II. We give the details of a design of a double peak optical filter needed for selecting the above two oxygen lines in order to record them in the same interferogram with minimum disturbance from the other continuum and discrete part of the NSBR.
- III. We present preliminary laboratory results with these interferometers and evaluate their capabilities.

A photograph of interference fringe pattern with the etalon of 2 cm spacer is shown in Fig. 2. An interferogram (shown in Fig. 1) has been obtained by the etalon of 0.5 cm spacer recording the anode pulse rate of a photomultiplier tube through a 0.6 mm pinhole, located at the centre of the central fringe. This was done during introduction of atmospheric air into the etalon chamber after evacuation. The interferogram is affected by several factors, mainly, the instrumental width and the pressure and Doppler broadening and the width and hyperfine structure of the spectral line. It can be fitted<sup>1</sup> by the theoretical model of FP intensity response at the central fringe which is a function of the phase  $\delta$  for a line of wavelength  $\lambda$  with finite natural width. In this expression, given below, we have taken into account about 40 harmonic terms.

$$I(\delta) = I_0 \frac{1-R}{1+R} \left\{ 1 + 2 \sum_{m=1}^{\infty} (Re^{-L})^m \sin c \frac{m}{N_S} \sin c \frac{m}{N_{A_0}} \exp \left( -\frac{m^2 [D^2 + G^2(T)]}{4} \right) \cos m\delta \right\} \quad (1)$$

where,  $R$  is the mirror reflectivity,  $L$  the coefficient of Lorentzian function,  $D$  the coefficient expressing the mirror flatness,  $G$  the Doppler broadening coefficient as a function of temperature  $T$ ,  $N_S$  and  $N_{A_0}$  the finesse coefficients due to mirror spherical curvature and aperture area of the central fringe, respectively.

The phase is given by,  $\delta = 4\pi dn / \lambda$ , where  $d$  is the etalon spacer thickness. Because the pressure broadening is much smaller than that of the Doppler in the case of the light source He-Ne 632.8 nm, we can obtain the

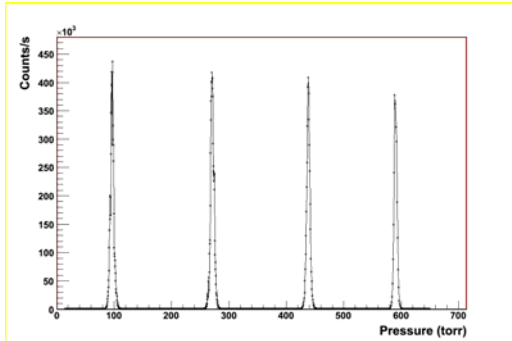
<sup>1</sup> The fit was performed by using the CERN MINUIT minimization routine from ROOT environment.

Doppler width of the spectral line as one of the free parameter of the fit. From the parameter  $G$  the temperature can be determined according to the following relations [5]:

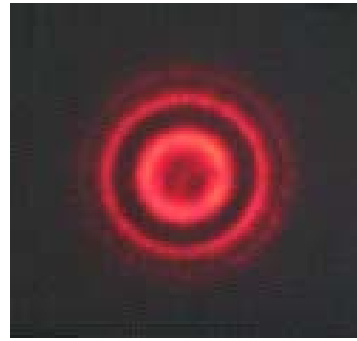
$$G = \frac{2\pi g}{(FSR)\sqrt{\ln 2}} \text{ or } g = \frac{G\sqrt{\ln 2}}{4\pi d}, \text{ where we replaced } FSR = \frac{1}{2d}. \text{ Thus, } T = M \left( \frac{g\lambda}{3.58 \times 10^{-7}} \right)^2, \text{ where } M \text{ is}$$

the molecular mass. In this method we oversimplified, and we have under preparation the more accurate approach which will take into account the modes in the laser. The above laboratory results on the Fabry-Perot etalons performance, indicate that they cannot probe with sufficient accuracy the scattering coefficient from aerosols when the light source scattered corresponds to line-width of the order of  $0.01 \text{ cm}^{-1}$  as can be available from a combination of a 532 nm Nd:YAG and appropriate optical parametric oscillator (OPO) [5]. Such a light source, when scattered by aerosols having masses several hundreds or thousands of an atmospheric molecule mass don't essentially broaden the laser's line-width. On the contrary, the elastic scattering of such radiation by air molecules leads to broaden due to Doppler effect spectrum with typical width of the order of  $1 \text{ cm}^{-1}$ . This necessitates the use of an etalon with spacer distance of around 5-10 cm so that there is enough spectral resolution to disentangle the narrow peak of aerosol scattering (of the order  $0.02 \text{ cm}^{-1}$ ) from the molecular scattering.

This is the next step of our research plan: The etalon is planned to be constructed of a tandem of 4 spacers, made of Zerodure, and the two etalon mirrors will be supported at the spacer assembly protubers, three for each mirror. The protubers corresponding to one of the mirrors will have to be temperature controlled, so that, the parallelism of the two mirrors is ensured to be at least  $\lambda/100$ .



**Figure 1.** A sample of pressure tuned interferogram obtained with the Queensgate FP etalon. The data samples are shown with open circles.



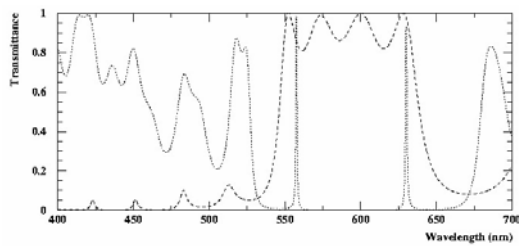
**Figure 2.** Interference fringe pattern with an etalon of SLS Optics Ltd with 2 cm spacer thickness and a He-Ne Laser.

Given the flatness of the order of  $\lambda/200$ , the finesse is mainly governed by the mirror reflectivity and can reach a typical value of around 25. Thus, the resolution of such an interferometer is expected to be equal to  $FSR/Finesse=0.002 \text{ cm}^{-1}$ . The analysis of the interferogram is based on: First, characteristic peak, due to the convolution of Doppler broadening from the scattering from the aerosol particulates and the spectral width of the OPO. Secondly, this peak is superimposed to the peak of the light scattered by the atmospheric molecules with characteristic width of the order of  $1 \text{ cm}^{-1}$ . Thus, we expect that the interferometer will be able to quantitatively study the level of aerosols in comparison to the molecular component.

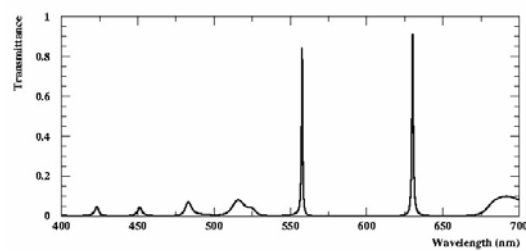
#### 4. Double peak optical filter

Below, we describe the considerations for using Fabry-Perot etalon for quantifying the NSBR lines at 557.7 and 630.0 nm. To use an interferometer for this purpose, we propose a double-peak optical filter with peak transmissions at the above two lines with FWHM of the order of 1 nm. Such a filter can be constructed by a

multilayer dielectric stack on a glass substrate, considering a tandem of all-dielectric Fabry-Perot filter and applying the method of *Simulated Annealing* for achieving the fine tuning of the peak positions. The results are seen in Fig. 3. This filter could be combined with a band-pass one in order to reduce the background in the extended region around the two peaks of transmittance (see Fig. 4).



**Figure 3.** The double narrow-peak transmittance for selecting the two atomic oxygen atmospheric lines at 557 and 630 nm (dotted line). The dashed line represents the transmittance curve of a 40-layer band-pass optical filter.



**Figure 4.** The resulting simulated transmittance of the two 40-layer filters. The transmittance in a wide spectral range is sufficiently reduced by this technique.

## 5. Conclusions and Prospects

This work aims at the understanding the benefits and limitations of use of high resolution spectroscopic techniques in analysing Lidar and night sky background radiation data in EAS telescopes. We obtained interferograms in a pressure tunable Fabry-Perot etalon and we fitted them to determine the Doppler width of a He-Ne laser. We are eager to test the data acquisition system with a 10 cm spacer etalon. The next step is to use a continuous wave laser with line-width less than  $0.01 \text{ cm}^{-1}$  and try to recover the required parameters from a mixture of molecular and aerosol sample in the laboratory. The preliminary data are encouraging but the necessity to probe the aerosol to molecular ratio with high spectral sensitivity and high signal to noise ratio, in each wavenumber slice, requires larger aperture etalons and collecting area of the receiving telescope of at least 40 cm diameter.

## 6. Acknowledgements

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## References

- [1] M. J. McGill, W. R. Skinner, and T. D. Irgang, "Analysis techniques for recovery of winds and backscatter coefficients from a multiple-channel incoherent Doppler Lidar", *Applied Optics*, Vol. 36, No.6, (1997) 1253-1268.
- [2] J. M. Vaughan, Adam Hilger, "The Fabry-Perot Interferometer", *Series on Optics and Optoelectronics*, pp 327-337.
- [3] F. Jacka et al, "A large-aperture high-resolution Fabry-Perot spectrometer for airglow studies", *J. Phys. E: Sci. Instrum.*, Vol. 13 (1980).
- [4] K. Shiokawa et al., "A two-channel Fabry-Perot interferometer with thermoelectric-cooled CCD detectors for neutral wind measurement in the upper atmosphere", *Earth Planets Space*, 55, 271-275 (2003).
- [5] P. B. Hays and R. G. Roble, "A Technique for Recovering the Doppler Line Profiles from F-P Interferometer Fringes of Very Low Intensity", Vol. 10, No. 1 *Applied Optics* 193-200 (1971).
- [6] L. A. W. Gloster, "Narrow-band b-BaB2O4 optical parametric oscillator in a grazing-incidence configuration", Vol. 12, No. 11 *J. Opt. Soc. Am. B*, 2117 (1995).