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A Fabry-Perot Interferometer prototype for use in Doppler LIDAR for atmospheric monitoring in EAS detection

E.FOKITIS[1], P.FETFATZIS[1] AND S.MALTEZOS[1]
[1]*National Technical University of Athens*
fokitis@central.ntua.gr

Abstract: A Fabry-Perot interferometer prototype is studied, as part of a Doppler LIDAR (DL) receiver, for determining the aerosol to molecular scattering ratio for use in EAS Fluorescence Detectors. The etalon of this instrument has a Free Spectral Range of 0.1 cm^{-1} and resolution in wavenumber 0.008 cm^{-1}. Possible additional use of the proposed DL receiver can be as a spectrally selective detector to measure the aerosol phase function normalized to the molecular phase function using a bistatic LIDAR. Both molecular and aerosol data are collected by the same DL receiver simultaneously as opposed to the Rayleigh or Raman LIDAR adopted in the atmospheric monitoring procedures in EAS fluorescence telescopes. The results from the characterization of the 0.1 cm^{-1} FSR etalon, presented in this work, are encouraging for the possibility for a constructing a DL receiver to measure the aerosol to molecular scattering ratio with better accuracy than the present techniques used in atmospheric monitoring for EAS fluorescence or atmospheric Cherenkov telescopes.

Introduction

In this work, we address the atmospheric monitoring issue from the point of view of the aerosol scattering coefficient. In the elastic LIDAR method, this signal is mixed with the molecular scattering signal leading to appreciable error in the determination of the aerosol scattering coefficient. We present, therefore the work towards the Doppler LIDAR based essentially on an appropriate Fabry-Perot interferometer [1], and namely an apparatus which can separate the aerosol and molecular scattering signals due to their significant differences in the spectral width since the molecular signal has much wider line width in the backscattered laser signal. The measurement system will contain two channels, namely the aerosol channel and the molecular channel. The signal for the molecular channel will be received from after the backscattered signal from a certain atmospheric height will be reflected from the Fabry-Perot etalon used for the aerosol channel. Therefore, the signal to be detected with the aerosol channel will be a combination of aerosol backscatter spectrum and the center of molecular backscatter spectrum. The signal to be detected with the molecular channel will be a combination of the wings of the molecular spectrum and the part of the aerosol backscatter spectrum that does not pass the high resolution etalon, see ref. [2]. The work that follows is divided in the following sections. Section 2 describes the characterization of the Fabry-Perot etalon with a He-Ne laser. Section 3 describes the Doppler width calibration using Cadmium lines. Section 4 contains the discussion and prospects.

Characterization of the Fabry-Perot etalon with a He-Ne laser

The principle of operation is the following: We are using He-Ne laser with frequency separation between the adjacent four longitudinal modes around 375 MHz [3]. The response of the 5 cm spacer etalon, provided by SLS Optics, is seen in Figures 1, 2 and 3. We have used here a commercial dSLR CCD camera, Nikon D40, to record the two dimensional fringe pattern and measure the light intensity distribution. These data can guide us to what is expected with the 5 cm spacer etalon which we used for most of this work. We clearly observe a pattern expected for the interference fringes following the diameter size proportional to the square root of the fringe order, with fine structure caused by the longitudinal modes of the laser. To quantify the results, we present the expected and measured fringe diameters using the formula:

$$D_n = 4f\sqrt{\frac{\lambda}{d}(n-\varepsilon)}$$

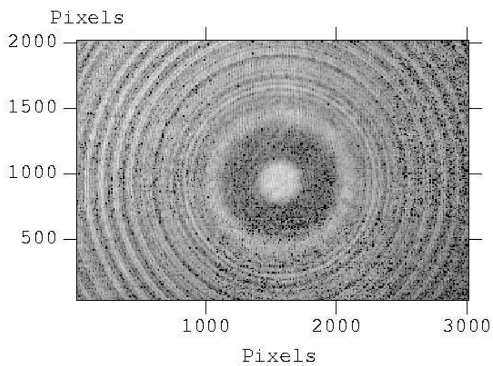

Figure 1: Two-dimensional interference pattern for He-Ne line at 632.8 nm .

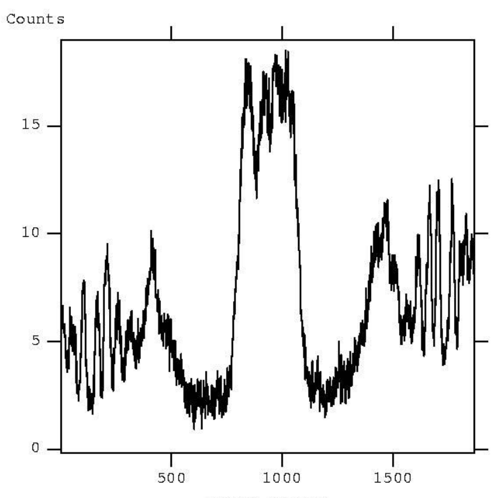

Figure 2: The intensity distribution of the interference fringe pattern, along y direction.

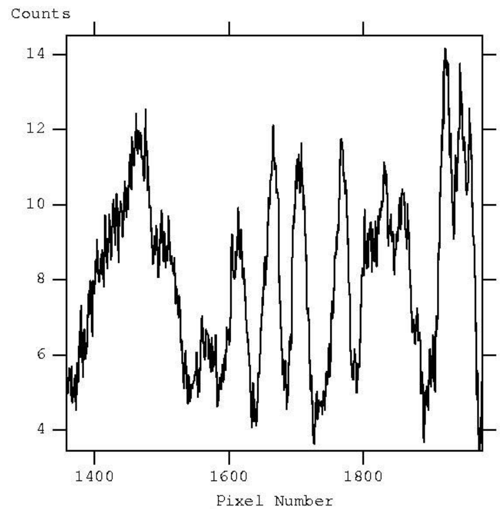

Figure 3: The intensity distribution, along y direction, showing details of Figure 2 in the area of 1350-2000 pixel number.

where D_n is the n^{th} fringe diameter, d is the spacer length of the etalon equal to 5 cm, λ is the laser wavelength equal to 632.8 nm, n the fringe number , and ε is a number between zero and one, related to the exact phase difference between successive transmitted rays belonging to the same wavelength. In this way, we determine the expected fringe diameters, and construct the following Table 1.

Table 1
Expected vs measured fringe diameter (in units of pixel number) for first 5 orders where the value of ε = -0.022 was used.

Fringe no.	1	2	3	4	5
calculated diameter	3.2	4.5	5.5	6.34	7.09
Measured diameter	3.2	4.5	5.5	6.2	7.0

Therefore, the finer structure in each interference order, must clearly be related to the longitudinal mode structure of the He-Ne laser. We are in the process to analyse the fine structure in order to extract the longitudinal mode structure of the specific He-Ne laser we used, and therefore look for possible non-linearities in our etalon.

Doppler width calibration using Cadmium lines

We have used the etalon in order to observe the three visible lines of the cadmium with the aid of appropriate optical filters. The two-dimensional fringe pattern is seen in Fig.4, corresponding to the Cadmium lines at 467 and 479 nm. The sharpness of the spectral lines depends on the Doppler broadening and the effective finesse of the interferometer.

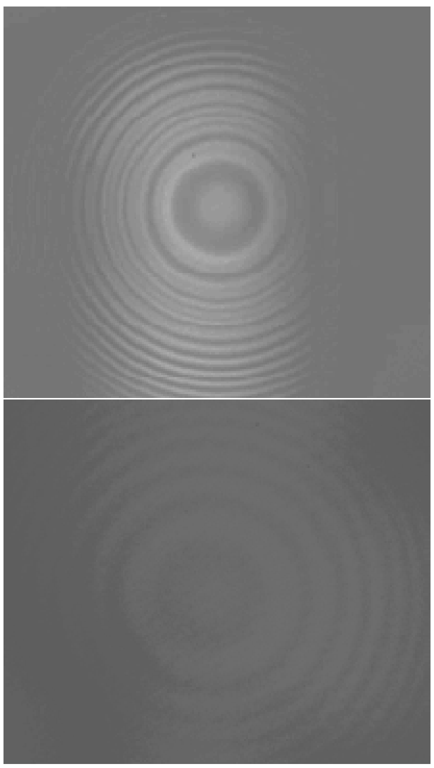

Figure 4: Two-dimensional interference fringe patterns for the total spectrum (upper) and for the two Cadmium blue lines (lower).

This is shown more clearly in Figures 5 and 6, where the intensity distribution in the horizontal and vertical direction, respectively.

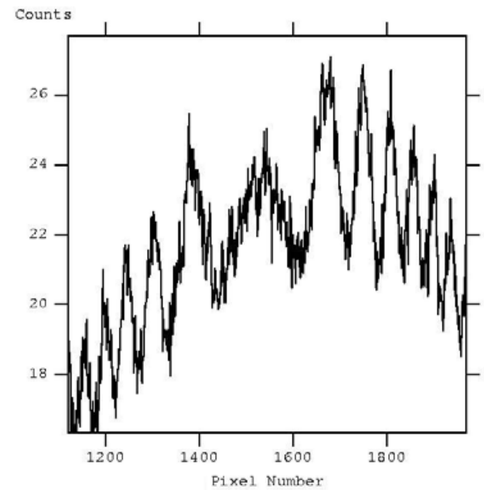

Figure 5: The intensity distribution of the interference fringe pattern recorded for two blue Cadmium lines along x direction.

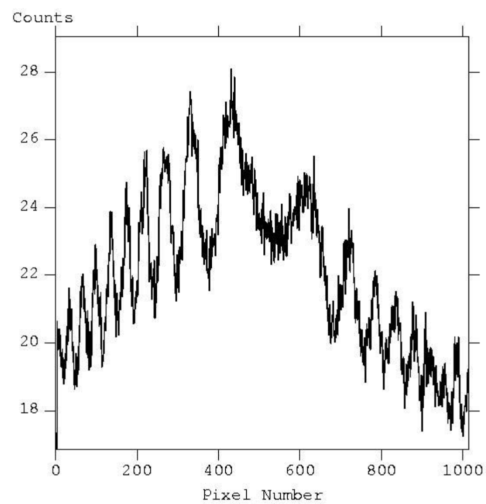

Figure 6: The intensity distribution of the interference fringe pattern recorded for Cadmium lines along y direction.

Using such data one might be able to extract information on the Doppler width of a spectral line of cadmium in the blue region. We know that the Doppler width can be estimated from the temperature and mass number. We therefore are aiming to compare our data with these of the literature in order to characterize the response of our etalon in nearly monochromatic but with well known spectral width, line.

Discussion and Prospects

We are planning to conduct tests using a parabolic 35 cm diameter mirror, focal length 1650 mm and f/number 5.5, using pulsed Nd:YAG or Argon ion lasers in order to characterize the performance of the 5 cm etalon as a prototype for Doppler LIDAR activity. We have started some tests to record interference fringe patterns with argon ion laser as a light source for the 5 cm spacer etalon. The apparatus is using low resolution predispersers for isolating the specific line of interest. We are considering the use of molecular Iodine filter, as described in [4], in order to stabilize the laser frequency to an acceptable spectral width for Doppler LIDAR.

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