A NEW ULTRAVIOLET SPECTROMETER FOR SO_2 MEASUREMENTS

S. MATTEI[1], S. PANACHIA[1], V. SCHENA[1], G. HOOVER[2]

[1]COnsorzio per la RIcerca su Sistemi di Telerilevamento Avanzato (CO.RI.S.T.A.),
P.le Tecchio 80, 80125 Napoli, Italy;
[2]Jet Propulsion Laboratory (J.P.L.), 4800 Oak Grove Drive, Pasadena, CA 91109, USA

ABSTRACT

In this report, we cover our attempts to describe a new prototype ultraviolet spectrometer that has been developed for use on the NASA SR-71 high altitude research aircraft. The instrument offers minimisation of weight, size and complexity as well as good flexibility and good spectral resolution. The scientific motivation was to enable the study of volcanic SO_2 emissions.

INTRODUCTION

Monitoring the chemical composition and flux of volcanic gas is one of the prospective methods for eruption prediction, since changes in the gas chemistry or flux are sensitive to the condition of magma ((Menyailov, 1975), (Casadevall et al., 1983)). Particularly, SO_2 is one of the primary gases released at volcanic vents and its changes seem to indicate movements of magma beneath the surface. It is therefore important to measure and quantify outgassing rates from all types of volcanic activity.

In order to better monitor volcanic sulphur dioxide flux, a new prototype airborne double ultraviolet spectrometer has been developed jointly by consortium CORISTA and Jet Propulsion Laboratory (JPL). The instrument is designed to be mounted on-board the NASA SR-71 high altitude research aircraft.

In this work, we describe the characteristics of the above mentioned instrument and the tests accomplished to identify its performances.

INSTRUMENT DESCRIPTION

The NUVS (Near UltraViolet Spectrometer) instrument is composed of three fundamental blocks:

- double spectrometer;
- ADC plug-in board for PC AT bus;
- compact personal computer.

The double spectrometer is one of the SD1000 series of spectrometers produced by the Ocean Optics, Inc., Florida. They are high performance, low cost, and miniature instruments ($6.7 \times 4.6 \times 2$ cm dimensions). The double spectrometer uses fiber mode containment design that provides good spectral resolution, high light throughput and low level of stray light. The fiber optic design permits easy configuration of the system and maximum flexibility. The SD1000 is made by two separate S1000 spectrometers, called Slave and Master. In our configuration, each spectrometer works in the spectral band 250–365 nm, and is arranged with two focusing mirrors of short focal length (42 mm) and a 2400 lines/mm blazed holographic grating. It is connected to a fiber optic of 100 μm core, 0.22 numerical aperture, coupled with a filter whose bandwidth is centered around

295 nm. The active sensor of each spectrometer is a UV-enhanced silicon 1024 active pixels CCD linear array labelled NEC µPD3575.
The instrument is coupled with the computer by a CMOS technology cabled electronics. The computer is equipped with a 386SX microprocessor at a 25 MHz clock and a stress-resistant 8 Mbytes solid state disk. The data acquired by the instrument are digitalized by the ADC acquisition card on 12 bits words and are transferred from the ADC card to the disk by the DMA on an ISA bus at 8 MHz frequency. The data are written in binary format to optimise the transfer rate.
The entire device is accommodated in a 40🕭25🕭20 cm^3 dimension aluminium case
In fig. 1, a block diagram of the instrument is reported, meanwhile fig. 2 shows the optical layout of one spectrometer.

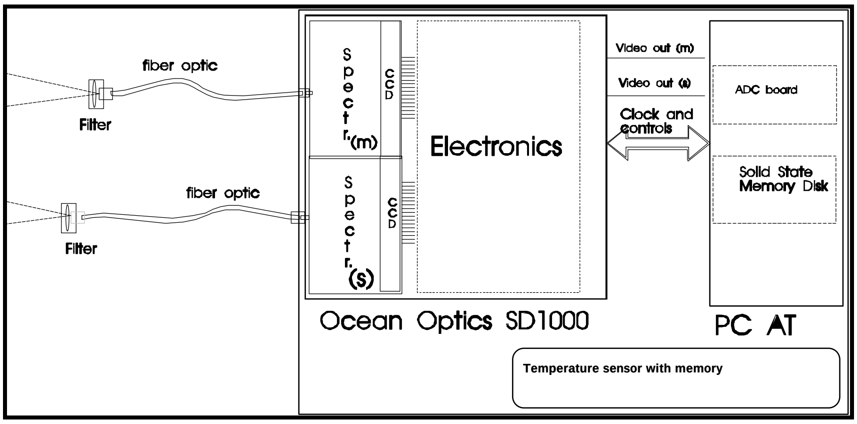

Fig. 1 - Block diagram of the instrument

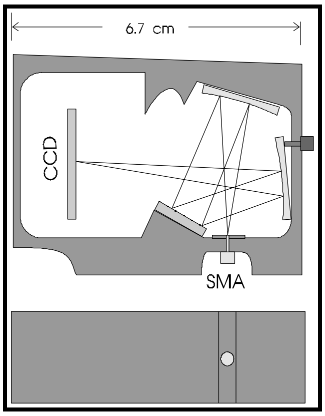

Fig. 2 - Spectrometer optical lay

SPECTRAL CALIBRATION

To perform the spectral calibration of NUVS ,we used a mercury lamp (PEN-RAY Mercury-Neon mixture Lamp at low pressure) of known spectrum. The distance between the lamp and the input of the fiber optics was chosen so that the maximum value of the spectrum did not saturate the instrument.
The spectral calibration procedure consists of acquiring mercury lamp spectra with our instrument, individuating the pixels that correspond to the higher digital numbers (DNs), and associating them to the corresponding mercury lamp emission lines center wavelengths ((Chrien et al., 1990), (Vane et al., 1990)). A least squares fit of the center wavelength versus the spectral band number was performed. The fitting curve we considered was a second order polynomial function:

$$l(p) = ap^2 + bp + c \qquad [1]$$

where p indicates the pixel number (i.e., the spectral band number) and l the wavelength.
The a, b and c coefficient's values we calculated are reported in the following table.

Coefficients	a	b	c
Master	-2.4883848e-05	1.5132098e-01	2.4446632e+02
Slave	-1.9997260e-05	1.4292014e-01	2.3944314e+02

Since the fitting coefficient a is very small compared to the others for both the master and the slave spectrometer, we can considered the dispersion as linear.

By the slope of the straight line fitting curve (fig. 3), we recovered the spectral sampling interval, defined as the spacing between the center wavelength of the individual spectral bands, of the two spectrometers. We found a spectral sampling interval of 0.1173 nm for the Master spectrometer and 0.1177 nm for the Slave spectrometer.
The measured mean spectral resolution, defined as the FWHM (Full Width at Half Maximum) of the spectra lines Bessel fitting curves, was of about 1.5 nm.

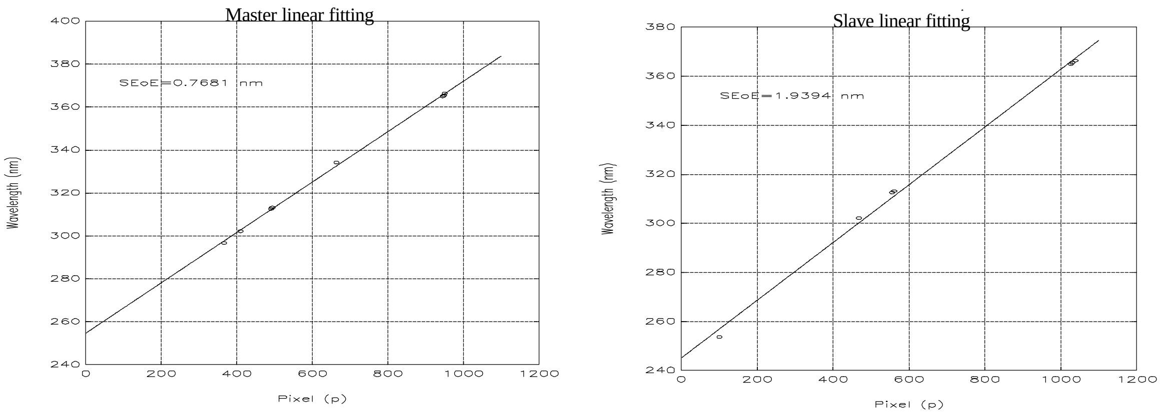

Fig 3 - Master and Slave spectral calibration

RADIOMETRIC CALIBRATION

The radiometric calibration is aimed to build a table of multipliers that, applied to the NUVS data, can convert the raw instrument digital numbers (DNs) to irradiance values.
We used an OPTRONIC LABORATORIES, Inc. 40 Watts and National Bureau of Standard certified deuterium lamp of known irradiance spectrum in the range 180÷400 nm.
Using the spectral calibration, the light transfer curves (irradiance versus wavelength), and the DN output acquired by the instrument, a table of multipliers was constructed using the following relation:

$$MUL(l) = \frac{I_{input}(l)}{DN_{output}(l) - DK_{output}(l)} \qquad [2]$$

where $I_{input}(l)$ is the irradiance value at a certain wavelength, $DN_{output}(l)$ the mean value of the DNs given by the instrument at the same wavelength, and $DK_{output}(l)$ the mean value of the dark current digital numbers. Therefore, applying the relation:

$$CDN(l) = MUL(l) \times \left[DN(l) - DK(l)\right] \qquad [3]$$

we can convert digital numbers to irradiance values.
At the moment, we are attending to calibrate the instrument in order to convert DNs to radiance values.

TEST-FLIGHTS

The Near UltraViolet Spectrometer has been developed for use on the NASA SR-71 high altitude research aircraft. The use of the SR-71 is critical since the aircraft has the unique ability to cruise at altitude in excess of 26 km, providing a platform that is above the zone of highest ozone concentration (20-25 km). This allows an essentially realistic simulation of a possible future orbital

observational environment with respect to sulphur dioxide and ozone, thereby allowing to explore SNR regimes.
Owing to its peculiar characteristics, small dimensions, fiber optics design and low power consumption, NUVS can be easily accommodated inside the SR-71, with the end of the fibers attached to the airplane's skin by means of an appropriate titanium mounting plate, containing also the filters. An on/off switch, for starting and stopping the instrument acquisition program, is mounted in the aft cockpit.
Our experience with the instrument includes three test-flights on the SR-71, during which it performed 'as expected'. It acquired data each 2 seconds during the flight and correctly transferred them to the memory. In fig. 3 spectra acquired by the Master spectrometer are reported.
However, several problems were put in evidence during the test-flights. In particular, it was pointed out that the dark current grew up, owing to the relatively high temperature reached during the flight by the instrument compartment (10°C up to 30°C), leading to a signal-to-noise ratio decrease.

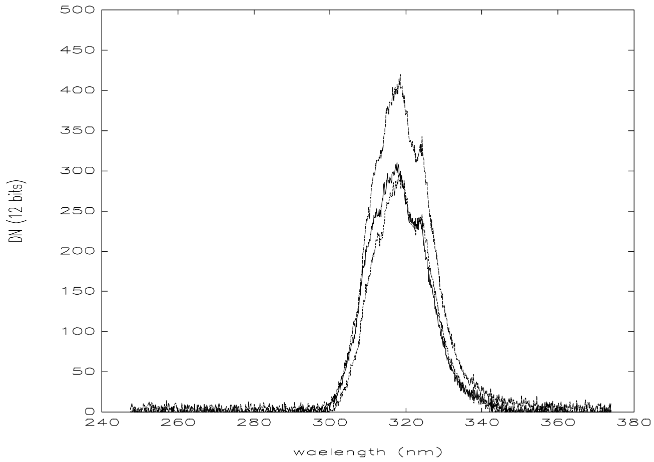

Fig. 3 - Raw data (digital numbers) of three spectra acquired during the first flight test by the Master spectrometer

CONCLUSIONS

A new ultraviolet airborne spectrometer for SO_2 measurements has been developed and tested. Its performances are quite satisfactory. This is not to say that we consider the development completed. There are indeed a number of improvements to take into account and that we are currently analysing, such as temperature noise check and thermal insulation.

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