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High resolution spectrometer for atmospheric studies: Filling in observation of sky spectra absorption lines

Piero Di Carlo (1,2), Massimiliano Barone(2), Ermanno Pietropaolo(2), Alfonso D'Altorio(2), and Guido Visconti (1,2)

(1) Centre of Excellence – CETEMPS, Università Degli Studi di L'Aquila, Italy

(piero.dicarlo@aquila.infn.it / Phone: +390862433118 / Fax: +390862433033)

(2) Dipartimento di Fisica, Università Degli Studi di L'Aquila, L'Aquila, Italy

Abstract

High resolution spectrometer for atmospheric spectroscopy studies has been developed at the University of L'Aquila, Italy. The instrument that is mainly assembled for tropospheric hydroxyl radical (OH) long path studies, is used to study the sky spectra absorption lines during the setting up and preliminary tests. The system includes a double pass Echelle spectrometer with focal length of 2 m, a prism premonochromator to select the orders of the spectrometer and a CCD as detector. The nominal dispersion of the instrument is 0.4pm at 308nm, where there are the absorption lines of OH. During the study of the solar lines of Fe, Ni and Ca around 558.8nm the dispersion was of 0.8pm/pixel and the resolution of 1.5pm. Observations of direct solar spectrum and sky spectrum show a filling in of the sky lines due to rotational Raman scattering. The controversial solar angle dependence of the filling in sky absorption lines is discussed. Results of the laboratory tests and atmospheric measurements are also reported.

Introduction

The removal of Fraunhofer structures in the measurements with absorption spectroscopy technique is complicated by the inelastic scattered light, Raman scattering, that modifies the depths of the Fraunhofer lines. This effect, observed in the early sixties and also known as Ring effect (Grainger and Ring, 1962), can be approximate as a filling in of the scattered solar lines as compared to the spectrum of direct solar light. Incorrect evaluation of the Ring effect is the principal limitation in the accuracy of the measurements with absorption spectroscopy technique of the trace gases like NO_2, O_3, OClO, BrO, SO_2, CO, HCHO (Vountas, et al., 1998). The observations of the Ring effect has had a long and tortuous history with controversial interpretations of the origin, now generally accepted as due to the rotational Raman scattering and the dependence of the lines depth with the solar zenith angle (Pallamraju et al. 2000, and reference therein). Observations with high resolution spectrometer could help for a more accurate determination of the filling in of the solar lines.

Instrumentation

The instrument is a SOPRA double pass Echelle spectrometer with 316 grooves/mm, focal length of 2m. It works at the 19^{th} order in the UV, in the measurements reported here, in the visible part of the solar spectrum, it works at the 10^{th} order. The premonochromator has a 50mm focal length and is in a Czerny-Turner setup. The aperture of the premonochromator input is f/5 and the output aperture is adapted to the spectrometer; it is used to select the orders in the Echelle spectrometer as well as to reduce the stray light with an efficiency of more than 70%. The detector is a front illuminated CCD with lumogen coating manufactured by Roper. The main characteristics of the CCD are: format 1024x256 imaging pixel, pixel dimensions 26x26 μm, dynamical range 16 bit, dark current: 0.5 e-/p/hr @ -120˚C and the cooling system with liquid nitrogen.

Discussion and conclusion

The observations reported here were carried during summer 2004 near L'Aquila (Italy) (42.35˚N, 13.38˚ E, elevation 750m). The measurements were made on clear as well as cloudy sky. To determine the Ring effect (RE) we calculate the difference between zenith scattered solar spectrum and direct solar sunlight. A parameter usually reported in literature is the fractional ring effect (FRE) that is defined as:

$$\text{FRE} = \text{RE}/(\text{RE}+\text{BC})$$

were BC is the background continuum obtained with a linear fit between the continuum regions on either sides of the absorption lines under consideration (Pallamraju et al. 2000).

Measurements during a clear day (July 6, 2004) show the FRE lower than 5% for solar zenith angle (SZA) below 70˚ for all the lines observed (558.67nm, 558.75nm, 558.78nm, 558.87nm). For SZA above 80˚ the 558.75nm line shows a FRE of 6% while other lines have a FRE of 17%.

The FRE for high solar zenith angle($>$80˚) is in agreement with Pallamraju et al.

(2000) that used an instrument with a resolution of 12pm while for low SZA($<70^\circ$) we observe a FRE that is about half of what reported in their work. Observations during August 23, 2004, with clear sky as during July 6, 2004, show FRE never above 10% for all the wavelength observed and very low ($<3\%$) FRE for SZA less than 70˚. During another day of measurements (August 23, 2004) on cloudy sky, we observed FRE values like the day before that was on clear sky.

The data reported in this work confirm the dependence of the Ring effect on solar zenith angle as well as the day-to-day variations due to sky conditions (Harrison, 1976; Conde et al., 1992, de Beek et al., 2001). Future works with these high spectral resolution data combined with theoretical models could help to better understand the mechanism of the Fraunhofer lines' filling in.

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