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A new relation between the central spectral solar H I Lyman α irradiance and the line irradiance measured by SUMER/SOHO during the cycle 23

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Abstract

The spectral irradiance at the center of the solar H I Lyman α ($\lambda_0 = 121.5664$ nm, referred to as Lyα in this paper) line profile is the main excitation source responsible for the atomic hydrogen resonant scattering of cool material in our Solar System. It has therefore to be known with the best possible accuracy in order to model the various Lyα emissions taking place in planetary, cometary, and interplanetary environments. Since the only permanently monitored solar irradiance is the total one (i.e. integrated over the whole Lyα line profile), Vidal-Madjar [1975. Evolution of the solar Lyman alpha flux during four consecutive years. Solar Phys. 40, 69–86] using Orbiting Solar Observatory 5 (OSO-5) satellite Lyα data, established a semi-empirical formula allowing him to deduce the central spectral Lyα irradiance from the total one. This relation has been extensively used for three decades. But, at the low altitude of the OSO-5 orbit, the central part of the solar line profile was deeply absorbed by a large column of exospheric atomic hydrogen. Consequently, the spectral irradiance at the center of the line was obtained by a complex procedure confronting the observations with simulations of both the geocoronal absorption and the self-reversed shape of the solar Lyα profile. The SUMER spectrometer onboard SOHO positioned well outside the hydrogen geocorona, provided full-Sun Lyα profiles, not affected by such an absorption [Lemaire et al., 1998. Solar H I Lyman α full disk profile obtained with the SUMER/SOHO spectrometer. Astron. Astrophys. 334, 1095–1098; 2002. Variation of the full Sun Hydrogen Lyman α and β profiles with the activity cycle. Proc. SOHO 11 Symposium, ESA SP-508, 219–222; 2004. Variation of the full Sun Hydrogen Lyman profiles through solar cycle 23. COSPAR 2004 Meeting], making it—for the first time—possible to measure the spectral and total Lyα solar irradiances directly and simultaneously. A new relation between these two quantities is derived in an expression that is formally similar to the previous one, but with significantly different parameters. After having discussed the potential causes for such differences, it is suggested that the new relation should replace the old one for any future modeling of the numerous Lyα absorptions and emissions observed in the Solar System.

Keywords: Atmospheres, composition; Comets; Interplanetary medium; Planets, general; Ultraviolet observations

1. Introduction

The spectral irradiance at the center of the solar Lyα line profile is the main excitation source responsible for the atomic hydrogen resonant scattering in cool material. If one wishes to model precisely the Lyα emissions occurring in planetary, cometary or interplanetary environments, this central spectral irradiance has to be known with the best possible accuracy at any given time. On the other hand, the only permanently monitored solar irradiance is the one integrated over the whole solar Lyα profile—either measured by near-Earth satellites, or deduced from its correlation with solar activity indexes. This was the reason why Vidal-Madjar (1975) analyzing the OSO-5 satellite Lyα data, proposed a semi-empirical formula (referred to VM75 relation in the following), relating the central spectral irradiance to the line irradiance of Lyα. In the present work, owing to solar Lyα

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spectra measured by SUMER/SOHO well outside the hydrogen geocorona, we present a new and more direct determination of the relation between both quantities.

2. Previous determination

At the 500 km altitude of the OSO-5 orbit, the observed central part of the solar Lyα line profile was deeply absorbed by a large column of exospheric atomic hydrogen, as shown in Fig. 1: the measurement made by a hydrogen resonance cell provided the central irradiance of the solar Lyα profile convolved with the absorption function of the geocoronal hydrogen column present between the spacecraft and the Sun. Therefore, the actual spectral irradiance was not directly measured, but rather estimated by confronting the measurements with simulations of both the geocoronal absorption and the unknown self-reversed shape of the central solar profile itself (Vidal-Madjar et al., 1973; Vidal-Madjar, 1975). Concerning the line irradiance, it was integrated over 10 nm and cross-calibrated with similar measurements made by other instruments. After corrections had been applied to take into account the aging of the H resonance cell and of the OSO-5 instrument, the following semi-empirical relation between the central spectral and the total photon irradiances was deduced from least-square calculations:

$$\frac{f}{10^{12}\ \mathrm{s}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{nm}^{-1}} = 0.54\left(\frac{F}{10^{11}\ \mathrm{s}^{-1}\,\mathrm{cm}^{-2}}\right)^{1.53} \pm 0.33. \quad (1)$$

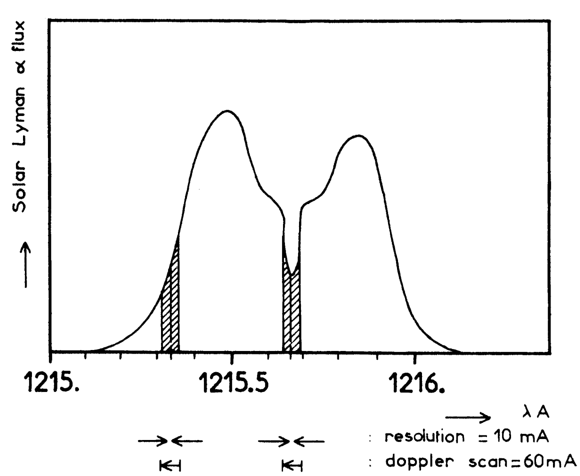

Fig. 1. This is a copy of Fig. 1 published by Vidal-Madjar et al. (1973). It shows the deep central absorption of the Lyα solar profile by the geocoronal atomic hydrogen present above the low altitude of the OSO-5 orbit. The global solar flux was measured in two separate channels in a 10.0 nm bandpass. A hydrogen resonance cell measured the observed central irradiance, i.e. convolved with the geocoronal absorption (central hatched region). A deuterium cell measured the irradiance corresponding to the thin hatched region in the blue wing, providing an estimate of the real shape of the solar profile. Concerning the central solar Lyα irradiance, it was obtained by comparing the data with model calculations simulating both the large self-reversal of the solar Lyα line, and the narrow and deep central geocoronal absorption.

In this relation, f is the central spectral Lyα photon irradiance and F the total Lyα photon irradiance. The uncertainty of ± 0.33 corresponds to the standard deviation between the observations and the calculated analytical relation: it only reflects the uncertainty on the calculated law relating the central to the total irradiance, but it assumes the absolute knowledge of the total irradiance and no potential bias due to the method itself.

The relation (1) was established during cycle 20, during four consecutive years from 1969 to 1972, corresponding to high to medium solar activity. On the other hand, it is worth to note that no correlation at all was observed during the minimum activity conditions,when the OSO5 satellite was reactivated from August 1974 to August 1975 (Vidal-Madjar and Phissamay, 1980).

3. Direct measurements of pure solar Lyα line profiles with SUMER/SOHO

Onboard the SOHO spacecraft, positioned well outside the hydrogen geocoronal envelope (at the L1 Sun–Earth Lagrange point), the SUMER spectrometer provided full-Sun Lyα profiles, exempt from any central geocoronal absorption (Lemaire et al., 1998, 2002, 2004). The measurement method has been extensively described in these papers. In brief, it essentially consists in using the scattering properties of the SUMER instrument: with very long exposure times, the telescope mirror scattering, although very small, is large enough to provide an adequate counting statistic (together with the low detector noise). The long tail scattering of the telescope mirror point spread function (PSF) was measured during ground tests (Saha et al., 1996). When the spectrometer slit is far outside the solar disk, the scattered radiation transmitted by the slit is a weighted contribution of the different areas on the disk, which can be estimated using this PSF tail (Lemaire et al., 1998, Fig. 1). To refine the data analysis, account was also taken of the fact that the scattered radiation entering the spectrometer slit can come from areas of the solar disk with different weights (Lemaire et al., 2002, Fig. 1). Finally, using the Lyα irradiance data given by the SOLSTICE satellite (Woods et al., 2000), Lemaire et al. (2002) obtained calibrated Lyα spectral irradiance profiles with relative uncertainties of $\pm 10\%$. Two examples of solar profiles measured by SUMER/SOHO are represented in Fig. 2.

4. The new directly measured relation between central and total solar irradiances

The line profile data collected during eight years of solar cycle 23 allowed us to measure directly the central Lyα solar irradiances as a function of the total ones. The results are shown in Fig. 3 in which the VM75 relation is also represented for comparison. Using the same units as in formula (1), the new analytical relation directly obtained from