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Solar H I Lyman α full disk profile obtained with the SUMER/SOHO spectrometer

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Abstract. An uncalibrated solar hydrogen Lyman α profile was obtained with the use of the spectrometer on SOHO. The collection of the light scattered by the telescope permitted to average the profile over the full solar disk. The profile taken at the L_1 Sun-Earth Lagrangian position is free of the central geocoronal absorption.
Then, taking advantage of the absolute flux measured by the SOLSTICE/UARS spectrometer, an absolute line profile intensity is derived, and is compared with previous observations at minimum solar activity.

Key words: Sun: chromosphere – Sun: UV radiation – line profiles

1. Introduction

The solar H I Ly α (121.567 nm) intensity profile was recorded for the first time in 1962 (Tousey 1963) on photographic emulsion. Since then the Lyman α line profile has been recorded on photographic emulsion many times (e.g., Bruner & Parker 1969; Bruner & Rense 1969; Bruner et al. 1973; Nicolas et al. 1976; Bruns et al. 1976; Basri et al. 1979 and results from following HRTS/NRL rocket flights). A few photoelectric profiles have been measured (e.g., White et al. 1976; Bonnet et al. 1978, Lemaire et al. 1978; from OSO8 and Fontenla et al. 1988 from SMM). However, only few attempts have been made to obtain an average profile over the solar disk (Lemaire et al. 1978).

The solar H I Ly α is of interest not only for solar and stellar physics , but also in interplanetary and cometary physics and in the upper atmospheric physics of Earth and planets.

In solar physics, the H I Ly α line is the main source of radiative losses in the upper part of the chromosphere and plays a prominent role in radiative transfer models of the atmosphere. The same role is true for stellar physics.
Interplanetary hydrogen is the most important contributor to the population of the interplanetary space. Indeed, the Sun is moving inside the local interstellar medium with a relative velocity about 26 km/s (Bertin et al. 1993; Linsky et al. 1993). This high velocity allows an important part of the interstellar hydrogen to penetrate well inside the solar system, despite the loss processes mainly due to photoionization and charge exchange with the solar wind protons. A significant interplanetary H I Ly α line is then observed in all directions of the sky, coming from resonant scattering of the strong core of the solar Ly α line by the interplanetary hydrogen (Quémerais et al. 1996; Puyoo et al. 1997). Interplanetary H I Ly α measurements contain much useful information concerning both the interstellar source and its interaction with the solar system. However, in order to correctly interpret such profile and intensity measurements in terms of interplanetary (and even interstellar) physics, it is necessary to accurately know the solar H I Ly α excitation source.

We present here the observation of a full solar disk H I Ly α profile obtained by the SUMER Extreme Ultraviolet Spectrometer onboard the Solar and Heliospheric Observatory (SOHO) spacecraft located at the L_1 Lagrangian position between Sun and Earth. Contrary to previous measurements made from low altitude orbits around the Earth, this observation is free of any geocoronal absorption in the core of the line. After a description of the method of observation we give the relative profile and then we use the solar H I Ly α flux measured by SOLSTICE on the UARS/NASA satellite to establish the absolute flux in the line profile. In the discussion section we make a comparison with previous results.

2. Observations

2.1. SUMER spectrometer properties

The SUMER spectrometer has been described in Wilhelm et al. (1995) and the in-flight performances are given in Wilhelm et al. (1997) and Lemaire et al. (1997). It covers the full 50 nm to 162 nm wavelength range with a stigmatic spectral resolution of 4.4 pm limited by the 26 μm pixel size of the detector in the first grating order.

An off-axis telescope mirror focusses the solar image on the spectrometer entrance slit. Several slits are available, ranging from 4 x 300 arcsec^2 to 0.3 x 120 arcsec^2. The light coming from the slit is collimated by an off-axis parabola, deflected by a plane mirror with adjustable incidence angle and collected by a concave grating in Wadsworth mount. The monochromatic diffracted light is focussed on a bi-dimensional detector. The

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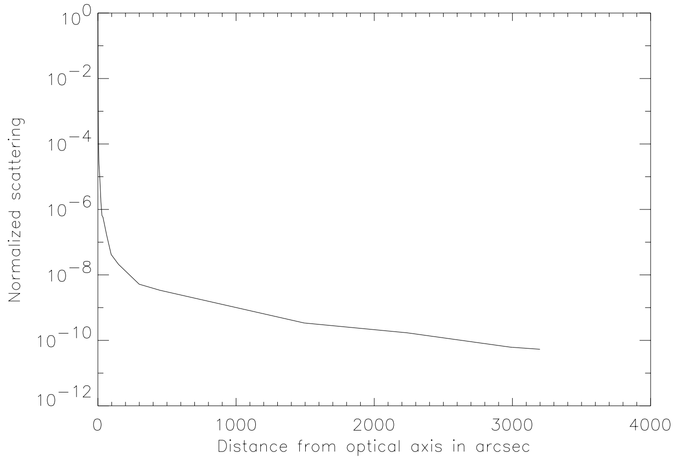

Fig. 1. Measured normalized scattered light distribution of the SUMER telescope as a function of focal plane distance (from Saha & Leviton 1993).

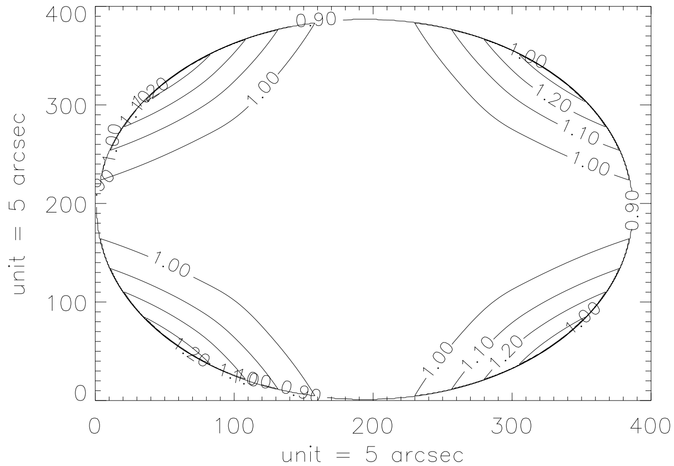

Fig. 2. Computed solar disk contribution to scattered light used to produce the Full disk profile.

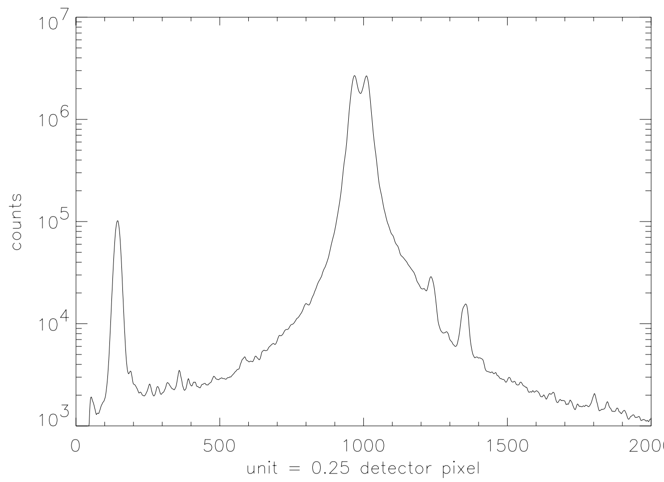

Fig. 3. Total raw H I Ly α 121.567 nm profile. The bright Si III 130.651 nm line is on the left. On the right O V 121.835 nm and Mg X 60.979 nm in second order are the brighest lines.

off-axis parabola-telescope can be rotated around its focal point to select any on-disk or off-disk solar structures in a field of $\pm$32 arcmin. In the laboratory, the telescope point-spread-function wings have been measured at 132.6 nm to several tens of arcmin (Saha & Leviton 1993) as shown in Fig. 1. At distances greater than 4 arcmin the wing (or scattered level) has a slow logarithmic variation and for an extended object, like the Sun, the level of scattered light measured at distances greater than 10 arcmin from the limb comes from a weighted contribution of all areas of the object (solar disk).

2.2. Observations: method and parameters

From in-flight measurements made all around the solar disk the distribution of scattered light is uniform to within a few 10% at the same radial distance. From the simulation it appears that the scattered light observed along a solar radius above the limb has a stronger contribution from the nearest hemisphere. Fig. 2 illustrates the computed weighted contribution to the 132.6 nm scattered light level at 4 positions located at X=$\pm$1500 arcsec and Y=$\pm$1500 arcsec from solar disk center (Y is along the south-north polar axis and X is perpendicular positive toward solar west). For the computation the solar disk has no limb brightening or darkening variation, and there is no polar coronal hole; it is a good approximation for the quiet Sun Ly α intensity distribution which appears constant (after averaging over supergranular cells and network) all over the solar disk. A series of spectra was recorded on September 15 and 16, 1996 between 19:32 UT and 3:41 UT with the 1 x 300 arcsec^2 slit. Four 2-hour exposures were recorded at each slit positions X=$\pm$1500 arcsec and Y=$\pm$1500 arcsec. The H I Lyα (121.567 nm) line was recorded in the central part of the A detector coated with KBr (with the highest sensitivity) and the full detector frame was transmitted to the ground.

3. Data reduction, calibration and resulting profile

The four spectral/spatial images were added and flat-field corrected following the procedure developed for SUMER data. Then, to take into account the spectral line deformations introduced by the detector, the image was destretched by using the standard programme developed by T. Moran for the SUMER detectors. After removing a few detector lines where dark pixels could not be recovered, the detector lines were added along the spatial image of the entrance slit to produce a reference spectral profile.

The full raw profile obtained on the central part of the detector (KBr coated) is displayed in Fig. 3. The bright Si III 120.651 nm (left) and Mg X 60.979 nm (right, second grating order) were used for the wavelength calibration. The accuracy of the wavelength scale is $\pm$2 pm. To obtain an absolute flux scale of the profile we have used the H I Ly α flux measured the same day by SOLSTICE (SOLar STellar Irradiance Comparison Experiment, Rottman et al. 1993) on the Upper Atmospheric

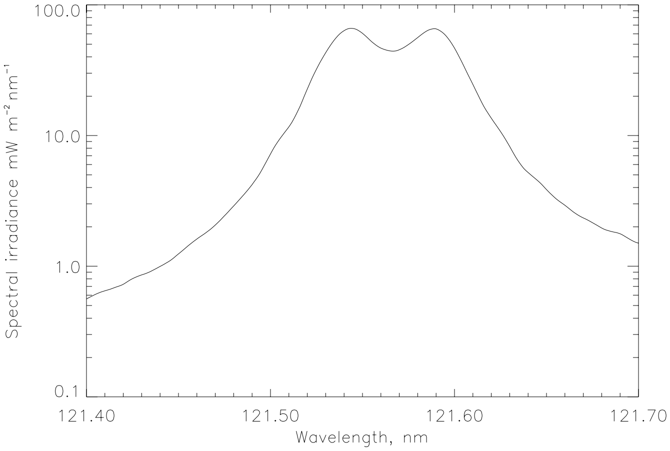

Fig. 4. Spectral irradiance of the H I Ly α profile on September 15, 1996.

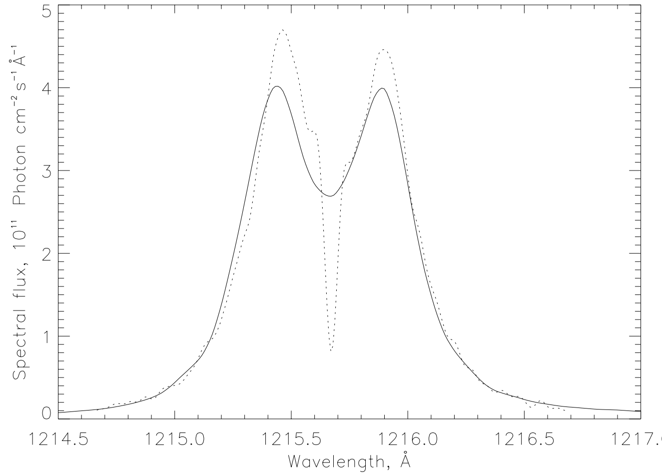

Fig. 5. Spectral flux of the H I Ly α SUMER profile on September 15, 1996 (solid line) compared to LPSP/OSO8 data taken on February 18, 1976, (dotted line) from Lemaire et al. (1978).

Table 1. Total H I Lyman α flux at 1 AU

	10.7 cm 10^{-22} W m^{-2} Hz^{-1}	Ly α 10^{11}photons cm^{-2} s^{-1}
LPSP (1976 Feb 18)	70.1	3.34 ±30%
LASP (1976 Feb 18)	70.1	3.70 ±40%
SOLSTICE (1996 Sep 15)	66.5	3.05 ±10%

Research Satellite (UARS). The 16 September 1996 flux was 3. 10^{11} photons cm^{-2} sec^{-1} (Rottman 1997). The accuracy of the measurement was established to be better than 10% (1 σ) and verified by Woods et al. (1996) who made a comparison between the two solar ultraviolet irradiance measurements on UARS and the measurements on the Space Shuttle with the Atmospheric Laboratory for Applications and Science (ATLAS) mission.

After normalization to the SOLSTICE bandpass, the absolute line profile spectral irradiance is displayed in Fig. 4.

4. Discussion

The OSO8 H I Ly α profile (Lemaire et al. 1978) was also obtained at the minimum of the solar activity cycle, and a comparison between the two profiles is of importance to have a better understanding of the shape and intensity of the line observed in similar conditions at 20 years interval.

The parameters of the 1976 observations of Lemaire et al. (1978) and Rottman (1981) are shown in Table 1 and compared with the 1996 observations. The two instruments on the 1976 rocket flights gave different results (different calibration methods). The Ly α LASP result (3.70 10^{11} ±40% photons cm^{-2} s^{-1}) is taken from Rottman (1981).

The 10.7 cm daily flux quoted for September 15, 1996 in Table 1 is an interpolation of the Penticton flux given for days Sept. 15 and 16 weighted by the variation of activity deduced from YOHKOH soft X-ray images obtained during the two days.

Within the uncertainty levels, the two measurements performed on February 18, 1976 are compatible and, as in Lemaire et al. (1978), we use the LPSP value to scale the profile shown in Fig. 5 (dotted line). On the same figure the present SUMER profile is overplotted (solid line).

The two profiles are very similar. The main difference comes from the central geocoronal absorption observed in the OSO8 profile. The better spectral resolution of the LPSP/OSO8 data (sampled every .83 pm with 2 pm resolution compared to 4.4 pm per pixel on SUMER data) gives a slightly smaller width of the profile, with higher peak to core ratio. The small bump seen in the blue part of the line core of the OSO8 line profile can be the combined result of the higher spectral resolution and of a residual error in the way the full Sun profile was obtained (weighted contribution of an average disk centre profile and an average limb profile). The detailed comparison is enhanced by the offset between the self absorption depth of the solar line and the geocoronal absorption.

For the excitation of hydrogen atoms in the interplanetary medium the flux at line center is critical. While there are regular observations of the integrated solar line flux (e.g. SOLSTICE and SUSIM on UARS), measurements at line center are scarce. Using data obtained by a hydrogen cell on OSO-5 at the beginning of the 1970's Vidal-Madjar and Phissamay (1980) have established several relations between the total line flux and the core flux for several levels of solar activity. The 1.1 ratio (total flux in photons cm^{-2} s^{-1} to spectral core flux in photons cm^{-2} s^{-1} $Å^{-1}$) measured here is compatible with their estimate for solar minimum activity level. This value is being used by modelers of the interplanetary hydrogen emission (e.g., Ajello et al. 1987; de Toma et al. 1997), but it is not clear how the relation evolves with increasing solar activity.

5. Conclusions

1. Using the unique capabilities given by the SUMER spectrometer and the SOHO spacecraft, we have recorded the

first high spectral resolution H I Ly α solar profile integrated over the solar disk without interference with the corona.
2. A comparison with a profile taken two solar cycles ago with the LPSP/OSO8 spectrometer in Earth environment shows that the shape of the full Sun profile taken at the minimum of the solar activity cycle is very similar.
3. From observations taken during the last two years and from future observations we expect to provide a better understanding of the variation of the H I Ly α line core needed to improve models of the interplanetary and interstellar hydrogen.

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