Solar irradiances and radiances of UV and EUV lines during the minimum of sunspot activity in 1996

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Abstract. Full Sun observations in UV and EUV emission lines were performed by SUMER (Solar Ultraviolet Measurements of Emitted Radiation) on SOHO (Solar and Heliospheric Observatory) in 1996. The radiometric pre-flight calibration of SUMER is traceable to a primary radiometric source standard - the electron storage ring BESSY. Based on this calibration, the irradiance values at SOHO and at 1 AU have been obtained for the lines He I (λ 584.33 Å), O V (λ 629.74 Å), Ne VIII (λ 770.41 Å), S V (λ786.47 Å), O IV (λ787.72 Å), S VI (λλ933.39, 944.52 Å), H I Ly ϵ (λ 937.80 Å), C III (λ 977.04 Å), N V (λ 1238.81 Å), Si I (λ 1256.52 Å), and C IV (λ 1548.20 Å). The spatially resolved measurements allowed good estimates to be made of the active region contributions to the irradiance of the quiet Sun. The centre-to-limb radiance variations of these lines have also been obtained from these measurements. For quiet solar conditions, a radiance spectrum was determined for wavelengths from 800 Å to 1500 Å near the centre of the solar disk.

Key words: Sun: corona – Sun:transition region – Sun: UV radiation – Sun: activity

1. Introduction

Observations of the Sun in ultraviolet (UV) and extreme ultraviolet (EUV) light have been performed on many occasions. Solar irradiance measurements have been presented, among others, by Watanabe & Hinteregger (1962), Hall et al. (1969), Hall & Hinteregger (1970), Heroux et al. (1974), Smith & Gottlieb (1974), Schmidtke et al. (1977), Rottman (1988), Chandra et al. (1995), Lean et al. (1995), Warren et al. (1996), and Woods et al. (1996) (see also the reviews by Hinteregger 1970; Timothy 1977; Schmidtke 1981; Lean 1987, 1991) and have provided an intermittend irradiance data base of the global Sun relevant to this wavelength range, although with different levels of absolute accuracy. Even if the orbiting UV instruments had been radiometrically calibrated before launch, serious sensitivity deteriorations plagued them, because the processes related to the polymerization of organic contamination products on optical surfaces were not fully understood. Rocket flights provide one means of obtaining a radiometric calibration, but require corrections for residual atmospheric absorption as a function of height throughout the flight.

The UV and EUV radiation is of great interest because (a) its intensity is closely related to the solar magnetic activity and is very variable on all time scales, and (b) it is completely absorbed by the high-altitude atmosphere of the Earth and, consequently, controls many processes in the upper atmosphere. Below 1027 Å, the O_2 photoionization limit, the EUV radiation is responsible for the daytime ionosphere and its heating, while longer wavelengths cause excitation and dissociation of the neutrals, and, below 1340 Å, also ionization of NO (Schmidtke 1984). Of particular importance are the variations of the radiation with the Sun's rotation period and the solar sunspot cycle. The solar rotation variability is to a large extent controlled by active region contributions (Lean & Repoff 1987; Lean et al. 1995; Warren et al. 1996). The solar cycle changes, although firmly established (e.g., Hinteregger 1977; Lean et al. 1995; Chandra et al. 1995; Warren et al. 1996), have not yet been understood in detail, and vary from cycle to cycle. For example, the HI Lyman α observations from the UARS (Upper Atmosphere Research Satellite) instruments SOLSTICE (Rottman et al. 1993) (Solar Stellar Irradiance Comparison Experiment) and SUSIM (Brueckner et al. 1993) (Solar Ultraviolet Spectral Irradiance Monitor) differ from the model predictions extrapolated with SME (Rottman 1988) (Solar Mesosphere Explorer) data from the previous solar cycle by about 50 % (Chandra et al. 1995).

Radiance observations can be found in, e.g., Dupree et al. (1973), Vernazza & Reeves (1978), Mango et al. (1978), Schmidtke (1984), Sandlin et al. (1986), and Brekke (1993).

Despite the many observations made, very little information has been available for the full Sun with high spatial and spectral resolution until the SUMER (Solar Ultraviolet Measurements

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of Emitted Radiation) instrument became operational on SOHO (Solar and Heliospheric Observatory) near the Sun-Earth Lagrange point L1, which is about $1.5 \cdot 10^6$ km sunwards from the Earth, unaffected by the Earth's atmosphere and magnetosphere. The resolutions provided by SUMER are important for a quantitative separation of active region contributions to the total irradiances in an emission line, for studies of their centreto-limb variations, but also for measurements of the spectral radiance. SUMER has produced full disk images in several UV and EUV lines. As a consequence of the high spatial resolution, however, acquiring each image in this mode requires between 3.5 and 31.5 hours. The design of SUMER was not optimized for the measurements to be presented here, but, as will be detailed later, the instrument has the advantage of a careful radiometric calibration traceable to the Berlin electron storage ring for synchrotron radiation (BESSY) and of experiencing no sensitivity deterioration over 20 months of more or less continuous operation, despite the open structures of the normal-incidence optical system and the detectors required for the wavelength range of SUMER. This stability has been achieved by the extensive chemical and particulate cleanliness programmes of SUMER and SOHO. We thus feel that the SUMER measurements near the minimum of the solar activity between cycles 22 and 23 are significant additions to the solar irradiance and radiance data base.

The centre-to-limb radiance variation also is an important parameter for the Sun (cf., e.g., Unsöld & Baschek 1991). This dependence and the related limb brightening of lines produced in optically thin regions are of interest for solar physics, comparison with stellar atmospheres, understanding the Sun's variable radiative output, and evaluating proxy models for the UV irradiance. Skylab observations in this context have also been obtained by Doschek et al. (1976a), Feldman et al. (1976), Kjeldseth-Moe & Nicolas (1977), and Mariska et al. (1978) for wavelengths longer than 1175 Å. Mango et al. (1978) presented centre-to-limb variations of HeI at 584 Å and other HeI and He II lines. From OSO-4 observations with a spatial resolution of 1', Withbroe (1970a) found centre-to-limb variations of approximately 4 to 6 (peak near limb to value at Sun centre) for the lithium-like ions N V, O VI, Ne VIII, Mg X, and Si XII. The optical thickness of the line-forming region for all these lines is $\tau < 1$. Specifically, Withbroe (1970b) derived $\tau = 0.03$ for N V, $\tau = 0.04$ for Ne VIII, $\tau = 0.12$ for O V. C III (λ 977 Å), on the other hand, is characterized by $\tau \approx 1$ with a limb brightening of ≈ 2.3 . For lines with wavelengths shorter than the HI Lyman edge, a significantly reduced limb brightening was found and attributed to spicule absorption. This is not effective for hot lines (e.g., Ne VIII and Mg X), which are formed at heights above the spicule regime. Very strong limb brightening above the HI Lyman edge has recently been reported for S VI $(\lambda 933 \text{ Å})$ by Lemaire et al. (1997).

The aim of this paper is to present the radiometric aspects related to the SUMER observations in such detail that their significance for solar radiometry can be assessed.

2. Instrumentation and calibration

The SUMER instrument has been described before the launch of SOHO (Wilhelm et al. 1995), and its performance characteristics, after several months of spacebased operation, have been summarized by Wilhelm et al. (1997a) and Lemaire et al. (1997). The SUMER detector A (detector B has not been used for full Sun observations) has two different photocathode areas (potassium bromide (KBr) and bare microchannel plate (MCP)), and a Lyman α attenuator of 1:10. The angular pixel size is approximately 1", corresponding to \approx 715 km on the Sun, and the spectral resolution element in first order is about 44 mÅ (22 mÅ in second order). The instrument can perform spectral scans in the wavelength range from 800 Å to 1610 Å (in first order) and record both the first order spectrum and the superimposed second order spectrum from 400 Å to 805 Å at pointing positions selected on the disk or off-limb in the low corona. It was demonstrated on the ground and verified during flight that the SUMER spectrometer has excellent stray-light characteristics and that there is no significant contribution of H I Ly α to other lines (except on the Ly α wings). Raster images of the solar disk and the off-disk corona were obtained by scanning the telescope mirror (see Table 1). The approximate angular dimensions of the spectrometer slit used for the full disk observation were $1'' \times 300''$. Scans were performed in step sizes of multiples of 0"3763 across the disk in eight swaths, each offset in heliospheric north-south direction by 270'' (290'' for the He I image of March 2, 1996), while the spectrometer readout was set to one or several emission lines.

Either line profiles, statistical moments of Gaussian approximations over certain spectral windows, or pixel sums over these narrow spectral windows were telemetred to the ground. The scan lengths of the swaths were adjusted so as to cover the solar disk and the lower corona in as short a time as possible. There was also a fast sweep mode possible, in which no spatial resolution was obtained in the heliospheric east-west direction. A rear slit camera (RSC) is available for alignment purposes by observing the solar limb or sunspots near 6000 Å in diffracted light.

SUMER was radiometrically calibrated in the laboratory with the help of a transfer standard against the primary radiometric source standard BESSY (Hollandt et al. 1996). The laboratory calibration was intended to measure the radiometric response of the SUMER system as far as mirror reflectivities and detector sensitivities were concerned. The primary calibration sequence was consequently designed in such a way that no vignetting of the calibrated photon flux occurred. When applying the resulting sensitivity curves to solar measurements it is therefore required to take the effects of field stops into account (telescope aperture, slit, and detector windows) as well as that of the Lyot stop together with the diffraction at the slit. This calibration was verified and refined for detector A with the help of the stars α and ρ Leonis and with line intensity ratios based on atomic physics data. It was found to be accurate within levels of relative uncertainties of \pm 15 % (1 σ) in the range from 540 Å to 1250 Å and \pm 30 % for longer wavelengths (Wilhelm et al. 1997b;

Table 1. Dates, times, durations, 10.7 cm fluxes, emission lines, and exposure parameters for full Sun images

Date 1996	Time (UT)	Duration (h:min)	F 10.7 $(10^{-22} \text{ W m}^{-2} \text{Hz}^{-1})$	Line	Wavelength (Å)	Window (Å)	Step ('')	Exposure (s)
Mar. 02	23:22	27:24	69.0	He I^a	584.33 ^b	0.55	1.505	7^c
June 26	15:50	00:20	74.2	$\operatorname{He} I^d$	584.33^{b}	1.10	sweep	920^{c}
June 26	19:04	00:20	74.2	$\operatorname{He} I^d$	584.33^{b}	1.10	sweep	920^c
June 26	19:39	04:40	74.2	He I^a	584.33^{b}	1.10	3.01	2^e
June 07	23:40	03:45	75.4	$O V^d$	629.74^{b}	1.09	3.01	2^e
June 14	11:46	03:45	69.8	$O V^d$	629.74^{b}	1.09	3.01	2^e
Feb. 02	02:10	16:03	74.2	Ne $VIII^a$	770.41^{b}	0.53	1.88	7.5^{c}
June 07	15:49	03:53	75.4	Ne $VIII^a$	770.41^{b}	1.05	3.01	2^e
June 16	11:31	03:53	69.0	Ne $VIII^a$	770.41^{b}	1.05	3.01	2^e
June 15	12:17	03:29	69.5	$\mathrm{S}\mathrm{v}^d$	786.47^{b}	1.05	3.01	2^e
June 07	15:49	03:53	75.4	0 IV a	787.72^{b}	1.05	3.01	2^e
June 15	12:17	03:29	69.5	O IV d	787.72^{b}	1.05	3.01	2^e
June 16	11:31	03:53	69.0	0 IV a	787.72^{b}	1.05	3.01	2^e
May 12	23:02	08:33	74.3	${ m S}$ VI d	933.39	2.23	1.505	3^f
Aug. 11	16:19	08:33	74.8	H i Ly ϵ^d	937.80	2.23	1.505	3^f
Aug. 11	16:19	08:33	74.8	${ m S}$ VI d	944.52	2.23	1.505	3^f
Jan. 28	22:40	25:27	71.8	$C III^a$	977.04	1.11	1.13 ^g	7.25^{c}
June 07	23:40	03:45	75.4	Nv^{a}	1238.81	2.18	3.01	2^e
June 14	11:46	03:45	69.8	$N v^a$	1238.81	2.18	3.01	2^e
June 07	23:40	03:45	75.4	$\operatorname{Si} I^d$	1256.52	2.18	3.01	2^e
June 14	11:46	03:45	69.8	$\operatorname{Si} I^d$	1256.52	2.18	3.01	2^e
Feb. 04	02:06	31:34	71.4	$\operatorname{C}\operatorname{IV}^d$	1548.20	2.10	1.88	15^c
June 07	15:49	03:53	75.4	$\operatorname{C}\operatorname{IV}^d$	1548.20	2.10	3.01	2^e
June 16	11:31	03:53	69.0	$\operatorname{C}\operatorname{IV}^d$	1548.20	2.10	3.01	2^e

^a Observed on the bare MCP

^b Second order

^c Line profiles available

^d Observed on KBr

^e 50 spectral pixel sums and three spatial pixels binned

^f Moment calculations onboard

^g Normal step mode

see also http://sohowww.nascom.nasa.gov/descriptions/experiments/sumer/radcal.html). The SUMER radiometric calibration procedure, the detector correction procedures for local gain depression caused by high single pixel count rates (Wilhelm et al. 1997a), and the correction for dead time effects of the analogueto-digital conversion electronics caused by high total detector count rates (Wilhelm et al. 1995; Hollandt et al. 1996) can be found at the above Internet address as well. It has also been demonstrated that the instrument output was stable for selected emission lines after many months of operation when observing regions of the quiet Sun at regular intervals (Hollandt et al. 1997; Schühle et al. 1998).

We will outline now the calibration and conversion procedure for the $1'' \times 300''$ slit. The telescope aperture is 90 mm × 130 mm. The diffraction effects and the vignetting by the Lyot stop, which have to be corrected for, have been determined by calculating the Fresnel diffraction at the slit. This and the geometrical configuration result in a second order polynomial approximation for the effective vignetting, V in %, as a function of the wavelength, λ in Ångström

 $V(\lambda) = 11.7 - 2.98 \cdot 10^{-3} \lambda + 2.80 \cdot 10^{-6} \lambda^2 \tag{1}$

The error contributions of these conversion procedures are already included in the uncertainties quoted above. The treatment of individual pixels is difficult, because of the variations of the size of the pixels with their position on the detector array. For the conversion of the spectra, we have assumed a mean pixel size of $26.5\mu m \times 26.5 \mu m$. The pixel sizes vary by up to \pm 5 % in either dimension. This error can be significantly reduced by considering the actual pixel size for the line or the spectral window under study on a case-by-case basis. For the full Sun images, on the other hand, we are in a much more favourable situation as we observe the full length of the slit on the detector. The measured slit length is (1.890 \pm 0.006) mm (corresponding to 299",2 with a focal length of 1302.77 mm) and its width (6.23 \pm 0.10) μ m (or 0'.'986). The solid angle covered is (295 ± 5) arcsec². We have to clip the slit image on either side in order to construct the correct swaths. This image compilation should be accurate to within \pm 2 % or better. The



Fig. 1. Full Sun image in the S VI (λ 933.39 Å) line formed at an electron temperature of 200 000 K observed on May 12, 1996 by SUMER. For details see text and Table 1. Note that, upon close inspection, the swaths of the scan can be identified

pixel size in the spectral dimension is of no importance as we are dealing with total line intensities.

3. Observations and data analysis

3.1. Full disk rasters in UV and EUV lines

The observations presented here were obtained as given in Table 1. Included are all raster images of the full solar disk taken by SUMER with the exception of 35 triple images in S VI ($\lambda\lambda$ 933, 944 Å) and H I Ly ϵ (λ 937 Å). This data set will be analysed in the context of a chromospheric network study. In Figs. 1 and 2 we show as examples the S VI and the Ne VIII images. The Sun in S VI exhibits an active region (AR) near its centre on May 12, 1996 and a well developed chromospheric network structure. The S VI radiation also shows a substantial limb brightening, which can clearly be seen in this figure. The other full Sun images (not shown here, but available at http://sohowww.nascom.nasa.gov/descriptions/experiments/sumer/gall.html) are also dominated by the chromospheric network structure. The limb brightening is not so pronounced in C III and much less in Ly ϵ . Polar coronal holes

(CH) can easily be identified both in Ne VIII and in He I. Ne VIII has an intense limb brightening only outside the coronal holes, whereas very little limb brightening or even darkening is characteristic for the optically thick He I line. All other lines treated here (with the exception of H I Ly ϵ and possibly C III) appear to be optically thin.

For all images but one (C III) special step or sweep modes were employed. In the special step mode, the slit is moved in units of 0^{''}.3763 over the telescope step size during the exposure time listed in Table 1. The purpose of this "smear step" mode is to provide a complete coverage of all areas of the Sun within a reasonable total duration and with acceptable count statistics. The C III image was exposed in normal step mode in which exposures are taken at single positions separated by an entire step. As a result, this image was slightly undersampled. In support of the SOHO underflight rocket (flight 36.147) flown in order to calibrate the Solar EUV Monitor (SEM) on SOHO (Hovestadt et al. 1995; Judge et al. 1998), two full disk observations were performed in a special sweep mode in He I (λ 584 Å) before and during the rocket launch, in addition to another full Sun image in He I. SEM observed the He II line at 304 Å. The comparison



Fig. 2. Full Sun in the Ne VIII (λ 770.41 Å) line formed at an electron temperature of 630 000 K. It was observed in second order of diffraction on the bare microchannel plate part of the detector on February 2, 1996. Note the north and south polar coronal holes and the dark features near the centre of the solar disk

between the He I and He II observations will involve many other instruments on SOHO and is beyond the scope of this paper.

Line profiles are available for He I, Ne VIII, C III, and C IV. All other lines have been integrated over 50 spectral pixels onboard or statistical moments have been calculated. The Sun was relatively quiet as one would expect at this phase of the solar cycle. This can be seen in the fourth column of Table 1 from the solar 10.7 cm flux levels ranging from 69.0 to 75.4. They are quoted from the Solar Indices Bulletin (NGDC) as adjusted Penticton final flux values, in solar flux units of 10^{-22} W m⁻² Hz⁻¹. The lowest flux yet observed was 62.6 on November 3, 1954.

We display in Figs. 3 and 4 sections of a quiet Sun (QS) spectrum observed near the centre of the solar disk on August 12, 1996 (only N v was recorded on June 8, 1996) showing the emission lines for which full Sun images are available (at other times). Most of the lines are well separated from neighbouring lines and this was the reason why we have selected them for the full Sun images. The spectra between 933 Å and 977 Å (S VI, H I Ly ϵ , and C III) cannot have second order contributions, because of the very low sensitivity of the instrument below 500 Å. The

other spectra could, in principle, contain radiation in both orders of diffraction. Therefore, both the KBr and the bare MCP data are shown. Whenever they differ, we have contributions of both orders.

As mentioned in Sect. 2, for bright lines and/or bright regions of the spectrum corrections for local gain depression of the detector MCP and for dead time effects have to be considered. The gain correction is dependent on the single pixel count rate and must ideally be applied before any other data handling procedures have been invoked. In some cases, these single pixel values are not available on the ground (when on-board curve fitting routines have been invoked). It is then required to study comparable solar features with full spatial and spectral resolutions in order to find approximate correction factors.

More complicated is the evaluation of those lines for which only the sum of 50 spectral pixels have been telemetred to ground (see Table 1). This was done in the interest of short total integration times, but requires significant corrections to be applied introducing additional error contributions. Specifically, we have estimated continuum and spurious line contributions to



Fig. 3. Spectral radiance, L_{λ} , of the quiet Sun near the centre of the disk on August 12, 1996 in selected wavelength ranges around the emission lines He I, O V, Ne VIII, S V, O IV, and S VI (λ 933 Å) in which full Sun images were taken. Lines with wavelengths below 800 Å have been observed in second order of diffraction. The spectral pixel values averaged over \approx 100 spatial pixels are shown by dots and/or open circles. Note the different scales and photocathodes (bare MCP: full circles and solid lines; KBr: open circles and dotted lines). In particular, it should be pointed out that the radiance scale pertains to radiation in the order, in which the principal line was observed. In Panels (a) to (c) the different background on KBr and the bare MCP is caused by the presence of first and second order radiation. The O V line is blended by a S II (λ 1259.53 Å) line. The line near 786.4 Å in Panel (e) could not be identified. The spectral windows sampled are shown by dashed lines (25 pixels) and dashed-dotted lines (50 pixels). The position of the windows with respect to the lines are known and have been indicated for He I and Ne VIII. For the other lines it had to be assumed that the lines are in the centre of the windows as commanded

the full Sun measurements from the spectra shown in Figs. 3 and 4 by multi-Gauss fits. They are valid for quiet regions near disk centre. Note that the continuum estimate, in general, consists of first and second order contributions, which, in most cases, can be separated by a comparison of KBr and bare MCP observations. The KBr/bare ratios are, however, close to unity both near 780 Å and 1560 Å (cf., Fig. 2 of Wilhelm et al. 1997b) and the separation for S V and O IV thus is not very accurate. By considering the effect of the Lyman continuum at 780 Å in second order, we can estimate a contribution of ≈ 4 % at 1560 Å. In the following analysis, we will determine the continuum contributions separately for the first and the second orders. It has then been assumed that (1) the continuum radiation does not exhibit any appreciable centre-to-limb variation and (2) the spurious line contributions obey the same centre-to-limb variation as the Si I (λ 1256 Å) line. In both cases we apply these corrections only for co-elevation angles $\vartheta > 37^{\circ}$. Below this value the data show many active region contributions. The differential contributions of the blend and continuum in the active regions can best be taken into account making the assumption that both contributions scale with the intensity of the line under study. This scaling is based on previously obtained unpublished SUMER observations indicating that in active regions the complete spectral range covered by our instrument increases in its level of intensity (see also Vernazza & Reeves 1978). Assumption (1) could be verified for continua at 812 Å and 1550 Å,

for which we found no variations in east-west direction (QS) and limb darkenings of less than 10 % in north-south direction (CH). The second assumption can be justified by the fact that Si I lines or lines of similar formation temperature contribute to the "blends". For each line the following correction parameters have been determined:

HeI (λ 584 Å)

He I, if observed on the bare MCP, requires a continuum correction of 7 % in total (of which 4 % are in second order) for a 0.55 Å window and 12 % (7 %) for 1.10 Å. In addition, a deduction of 1 % is needed to account for blends of N I lines in first order and possibly another unidentified line. On KBr and with a 1.10 Å spectral window, the continuum radiation was 31 % (18 %) and the blends contributed 4 %.

Ο V (λ 629 Å)

The O V line, observed on KBr in second order during the same scan as the strong Si I (λ 1256 Å) line in first order, can only be separated from the background with difficulties. Several weaker Si I lines and a S II line fall into the integration interval. Consequently, we estimate a high blend contribution of 37 % at disk centre, of which 10 % could be attributed to the S II (λ 1259.53 Å) blend by comparing the responses on KBr and the bare MCP. The continuum adds another 15 % (3 %) to the background correction.



Fig. 4. Same as Fig. 3 for the lines H I Ly ϵ , S VI (λ 944 Å), C III, N V, Si I, and C IV, all observed in first order of diffraction. Some neighbouring lines are identified. The windows for C III and C IV are shown in their measured positions. The S VI (λ 944 Å) line is blended by a Si VIII line requiring a substantial correction (see Table 2)



Fig. 5. (a) Geometrical relation of the solid angle element, $d\omega$, to the surface element, $d\sigma$. (b) With Eq. (5), a special surface element, $d\sigma$, as shown, can be selected. Two azimuth angles, ψ , (north and south) are indicated, but the radiance is not dependent on ψ in this case

Ne VIII (λ **770** Å)

The strong Ne VIII line is rather isolated and is not blended at all as far as we can determine. A Gaussian fit to the Ne VIII line demonstrated that a continuum correction of 7 % (0 %) was required for the 0.53 Å window and 13 % (1 %) for the 1.05 Å window.

S V (λ 786 Å)

Only the pixel sum over the 1.05 Å window is available on KBr. The corrections required are 25 % (1 %) for the continuum and 19 % for blends.

Ο ΙV (λ 787 Å)

The O IV line has been observed both on the bare MCP and

on KBr as sum over 1.05 Å windows. On KBr a continuum correction of 32 % (1 %) and blends of 7 % have been estimated. The corresponding figures for bare are 26 % (1 %) and 7 %.

S VI (λ **933** Å)

The moment calculations for the S VI (λ 933 Å) line, observed on KBr, were done onboard using a Gaussian fit routine over 50 spectral pixels. With the same routine we have verified for sample spectra taken in quiet Sun areas that the method leads to a good determination of the line intensity provided gain and dead time corrections of 2 % each are added. The onboard routine performed a correction of about 6 % for the continuum and 1 % for blends. The S VI gain corrections have been estimated for quiet Sun regions and may underestimate the active region and limb corrections by a few percent. There is a blend contribution by the He II Ba 11 line at 933.444 Å, which could not be removed. Comparison with the He II Ba 10 and 12 lines indicates that this contribution is approximately 5 %.

H I Ly ϵ (λ 937 Å)

As for S VI moment calculations were performed and a continuum of 5 % has been subtracted onboard. In addition, a line blend contribution of 5 % had to be deducted on the ground. Gain and dead time corrections of 2 % each have also been estimated and implemented for this line.

S VI (λ **944** Å)

This S VI line, also observed on KBr, was treated onboard with the same procedures as the S VI line at 933 Å, but it is weaker and blended by a coronal line. We find a continuum correction of 19 % (done onboard) and a blend of 22 % (subtracted on the ground) identified as Si VIII (λ 944.47 Å). A dead time correction of 1 % was applied.

Table 2. Corrections and relative uncertainties (1 σ levels) for the full Sun irradiance measurements. Corrections in parentheses have been performed aboard SOHO. The continuum and blend entries give the disk-averaged corrections after application of the correction procedure outlined in the text. AR and CH corrections have been applied to derive the quiet Sun values

Line	Corrections (%)							Uncertainties (%)			
	Cont1	Cont2	Blend	Gain	DT	AR^{a}	CH^{a}	Sens. ^b	Swath	Correc.	Total ^c
He I^d	-9	-5	-2	_	_	-1	4	15	2	3	15
He I^e	-15	-9	-2	_	_	-3	6	15	2	5	16
Ov	-13	-3	-39	_	_	-6	1	15	2	12	19
Ov	-13	-3	-39	_	_	-3	-	15	2	12	19
Ne $VIII^d$	-6	_	_	_	_	_	11	15	2	4	16
${ m NeVIII}^e$	-12	-1	_	_	_	-1	12	15	2	5	16
${ m Ne VIII}^e$	-12	-1	_	_	_	-1	12	15	2	5	16
SV	-24	-1	-22	_	_	-1	-2	15	2	9	18
O IV f	-24	-1	-8	_	_	-2	-	15	2	8	17
O IV ^g	-31	-1	-8	_	_	-	-1	15	2	10	18
$\mathrm{O}\mathrm{IV}^f$	-24	-1	-8	_	_	-1	_	15	2	8	17
S VI (933 Å)	(-4)	_	(-1)	2	2	-7	5	15	2	3	16
H i Ly ϵ	(-6)	_	-7	2	2	-2	3	15	2	2	15
S VI (944 Å)	(-14)	_	-19	_	1	-1	9	15	2	9	18
CIII	-1	_	_	30	10	-2	-1	15	2	10	18
Νv	-36	-4	-5	_	8	-1	8	15	2	14	20
Νv	-36	-4	-5	_	8	_	7	15	2	14	20
Siı	-39	-	-15	_	5	-1	1	30	2	13	33
Siı	-39	_	-15	_	5	_	_	30	2	13	33
CIV	-18	-1	-9	_	_	-1	4	30	2	9	32
CIV	-23	-1	-10	_	_	-4	5	30	2	10	32
CIV	-22	-1	-10	_	_	-3	5	30	2	9	32

^a See also Table 4, where the AR contributions are listed as well as the CH deficiencies.

^b Includes relative uncertainties of radiometric calibration, optical surfaces, stops and apertures.

^c The errors introduced by the count statistics are negligible. The fast scans produced $\approx 3.5 \cdot 10^6$ counts each, all other images at least five times more.

^d 25 pixel window.

^e 50 pixel window.

^{*f*} On bare MCP.

^g On KBr.

\mathbf{C} III (λ 977 Å)

This line is so isolated that it can be summed in the spectral dimension with only 1 % of continuum reduction, but, due to the high count rates (even if observed on the bare MCP), corrections of 30 % for gain and 10 % for dead time effects have to be performed.

N V (λ 1238 Å)

For this line only spectral pixel sums are available. We estimated a continuum contribution of 44 % (5 %) and blends of 5 %. The dead time correction used was 8 %.

Si I (λ 1256 Å)

The spectral pixel sums of this line contain significant blends (15%) and a rather high continuum contribution of 40% (0%). A dead time correction of 5% was performed as well.

C IV (λ **1548** Å)

The C IV images had to be corrected with a continuum value of 29 % (1 %) and blends of 11 %.

The entries in the first three columns of Table 2 give the resulting corrections for the full Sun during the integration of the disk images in the spatial regime. The continuum corrections are shown separately for first and second order. If, for a specific application, the total irradiances in the windows defined in Table 1 are required, they can be obtained by reversing the corresponding continuum and blend corrections. Let us take the first line in Table 2 as example (He I observed in a 25 pixel window corresponding to 0.55 Å in second order). If we want to know the total radiation in the window around 584 Å, we have to modify the quiet Sun value by a factor of 1/0.95 to account for the 5 % second order continuum radiation. For the first order line C IV at the end of Table 2, for instance, we find a first order continuum radiation of 22 % and a blend contribution of 10 %. The quiet Sun value thus has to be adjusted by a factor of 1/0.68 to get the total radiation in the 2.1 Å window around 1548 Å. Gain depression and dead time ("DT") corrections are listed according to the explanations given above and are valid for the centre of the solar disk. Before we describe the integration



Fig. 6. Centre-to-limb variation, ρ_{λ} , averaged over sections of concentric circles, as a function of the co-elevation angle ϑ and the projected heliocentric distance (sin ϑ) for the lines C III, S VI ($\lambda\lambda$ 933, 944 Å), C IV (February 4, 1996), Si I (June 14, 1996), and N V (June 14, 1996). The plots are normalized with the normalization factors shown. Multiplication of ρ_{λ} with the corresponding factor gives the spectral radiance, L_{λ} , in mW m⁻² sr⁻¹. Above the "limb" (defined at the photospheric limb position), the radiance is plotted as a function of height above the limb in arcseconds. The active region contributions can clearly be identified. Quiet Sun (QS = 2 · 124° sectors, solid lines, full circles) and coronal hole (CH = 2 · 56° sectors, dotted lines, open circles) curves are displayed. Individual integration points are shown where feasible. The function $f(\vartheta_{\rm UV}) = 1/\cos \vartheta_{\rm UV}$ is plotted for comparison assuming $\vartheta_{\rm UV} = 90^{\circ}$ at a height of 10″. It is repeated for each line for co-elevation angles $\vartheta < 37^{\circ}$ (vertical dashed line) as an estimate of the quiet Sun level near the centre (dashed lines)

in detail, some definitions and derivations of relevant relations might be in order:

The differential spectral radiant flux at wavelength λ can be written as

$$d\phi_{\lambda} = \frac{dQ}{dt \, d\lambda \, d\sigma} = L_{\lambda}(\vartheta, \psi) \, \cos \vartheta \, d\omega \tag{2}$$

where Q is the radiant energy, L_{λ} is the spectral radiance, ϑ is the co-elevation angle of $d\omega/d\omega$ (the direction of the solid angle $d\omega$) with the normal on the surface element $d\sigma$, and ψ is the azimuth angle of $d\omega$. The geometry is sketched in Fig. 5(a) for an arbitrary angle ψ . The spectral element is $d\lambda$, and dt is the time interval. The solid angle element is $d\omega = d\vartheta \sin \vartheta \, d\psi$ and the outward spectral radiant flux at wavelength λ becomes

$$\phi_{\lambda}^{+} = \int_{\psi=0}^{2\pi} \int_{\vartheta=0}^{\frac{\pi}{2}} L_{\lambda}(\vartheta,\psi) \cos\vartheta \sin\vartheta \, d\vartheta \, d\psi \qquad (3) \quad I_{\lambda} = 2\pi \operatorname{R}_{\odot}^{2} \int_{\vartheta=0}^{\frac{\pi}{2}} L_{\lambda}(\vartheta) \cos\vartheta \, \sin\vartheta \, d\vartheta$$

Eq. (2) can be re-written to give the differential spectral radiant intensity

$$dI_{\lambda} = \frac{dQ}{dt \, d\lambda \, d\omega} = L_{\lambda}(\vartheta, \psi) \, \cos \vartheta \, d\sigma \tag{4}$$

If L_{λ} is not dependent on the azimuth angle, ψ , then

$$L_{\lambda}(\vartheta,\psi) = L_{\lambda}(\vartheta) = L_{\lambda}(0) \rho_{\lambda}(\vartheta); \quad \rho_{\lambda}(0) = 1$$
 (5)

where $L_{\lambda}(0)$ is the spectral radiance at the centre of the disk and $\rho_{\lambda}(\vartheta)$ defines the centre-to-limb variation. With $d\sigma = 2\pi R_{\odot}^2 \sin \vartheta \, d\vartheta$ for the Sun as a sphere, as shown in Fig. 5(b), we can integrate Eq. (4) over ϑ and find the spectral intensity, I_{λ} , emitted towards the observer from the full disk as

(6)



Fig. 7. Same as Fig. 5 for the lines S V, O V, O IV (June 16, 1996), Ne VIII (February 2, 1996), H I Ly ϵ , and He I (March 2, 1996). The function $1/\cos \vartheta_{\rm UV}$ was not a good fit at disk centre for Ne VIII, H I Ly ϵ , and He I, where $f(\vartheta_{\rm UV}) = \text{const provides a better approximation}$

where R_{\odot} is the solar radius in the emission line under consideration. Finally, we obtain the mean spectral radiance

$$\bar{L}_{\lambda} = \frac{I_{\lambda}}{\pi R_{\odot}^2} = 2 \frac{L_{\lambda}(\vartheta_o)}{\rho_{\lambda}(\vartheta_o)} \int_{\vartheta=0}^{\frac{1}{2}} \rho_{\lambda}(\vartheta) \cos \vartheta \sin \vartheta \, d\vartheta \qquad (7)$$

where $0 \leq \vartheta_o \leq \pi/2$.

Eq. (3) can be integrated over ψ , after the substitution according to Eq. (5), to give

$$\phi_{\lambda}^{+} = 2\pi \frac{L_{\lambda}(\vartheta_{o})}{\rho_{\lambda}(\vartheta_{o})} \int_{\vartheta=0}^{\frac{\pi}{2}} \rho_{\lambda}(\vartheta) \cos \vartheta \sin \vartheta \, d\vartheta \tag{8}$$

By comparing Eqs. (7) and (8), we get

$$\bar{L}_{\lambda} = \phi_{\lambda}^{+} / \pi \tag{9}$$

We can measure the irradiance per wavelength interval

$$E_{\lambda} = \bar{L}_{\lambda} \, d\omega' \tag{10}$$

and thus can determine \bar{L}_{λ} with

$$d\omega' = \frac{\pi R_{\odot}^2}{r^2} \tag{11}$$

where, in our case, r is the distance from the Sun to SOHO. Whereas for stars the mean spectral radiance, \bar{L}_{λ} , or the spectral irradiance, E_{λ} , is all that can normally be observed, for the Sun the spectral radiance, L_{λ} , can be measured as a function of ϑ .

We will use the following units for L_{λ} and the quantities defined in Eqs. (2), (4), and (10): L_{λ} in W m⁻²sr⁻¹ per emission line, ϕ_{λ} and E_{λ} in W m⁻² per line and I_{λ} in W sr⁻¹ per line, but will not spell out "per line" in tables and diagrams. If there is a need to give the spectral radiance, L_{λ} , per wavelength interval, we will use the unit W m⁻²sr⁻¹Å⁻¹.

We perform the integration of the full Sun images in concentric circles in steps of 1" in order to determine the irradiances. As a consistency check, we also summed all pixels and obtained total full Sun figures in agreement with the previous scheme to within 1 %. By looking at the full disk images, in particular of Ne VIII, it can be seen that, in general, L_{λ} is not independent of ψ , and ϕ_{λ}^+ is not a constant over the surface of the Sun. More sophisticated schemes than outlined above are therefore required. As an approximation, we have also integrated the images over concentric circles broken up in sectors defined by the extensions of the polar coronal holes (specifically, we found a half angle of 28° around the poles). In Figs. 6 and 7 are shown



Fig. 8. Histograms of the logarithm of the radiances for the emission lines in quiet Sun regions together with Gaussian fits (shown with the resolution of the data points). The bin size was selected to be $0.1 (= \log 1.259 = \log 10^{0.1})$. All pixel with counts > 0 have been considered

the spectral radiances of the lines averaged along sectors of concentric circles as a function of the co-elevation angle ϑ . Besides the averaging introduced by the method of integration, we have smoothed the profiles over 2''. It should be pointed out that the method critically depends on an exact registration of the limb pixels with regard to the limb radiance obtained. As a consequence, the maxima near the limb appear to be underestimated for NV, CIV, and SVI, the lines with the narrowest limb brightening curves. Nevertheless, we find centre-to-limb variations of more than a factor of ten for some lines. In order to obtain an idea about the highest centre-to-limb variations, observable with the SUMER resolution of $\approx 1''$, we looked at limb crossings of the slit in the north and south coronal hole regions in the S VI (λ 933 Å) and C IV lines and found very narrow maxima with ≈ 4 spatial pixel (full width at half maximum) and centre-to-limb values of 10 to 25 for S VI and 8 to 15 for C IV.

Contributions of active regions can readily be identified in these plots, and the mean radiance in the observed emission lines can be established for the quiet Sun. Such estimates have been indicated by dashed lines. Levels 5 % higher than the mean values are considered to be active region contributions. He I, Ne VIII, S VI, H I Ly ϵ , N V, and C IV show distinctly less limb brightening in polar coronal holes compared to quiet Sun conditions at lower solar latitudes. The lines O V and Si I do not exhibit a difference of more than 5 % of the limb brightening for regions inside coronal holes compared to quiet Sun areas. S V, O IV, and C III have higher limb brightening values in coronal holes than in quiet Sun regions. It is also possible to estimate coronal hole deficiencies. They are positive for SV, OIV, and C III, as one would expect from the stronger limb brightening of these lines near the poles (negative correction in Table 2). Of course, it would be interesting to study the various features (QS, AR, CH) in more detail in all full Sun images available, but this is



695

Fig. 9. The values of the standard deviation, σ , given in Table 3 and of the histograms shown in Fig. 8 are plotted versus the temperature of maximum ionic abundance for ions, and the approximate line formation temperature for lines emitted by neutrals. Continuum radiation is assumed to be emitted at 6 000 K near 1500 Å and at 10 000 K near 1000 Å. Bin size as defined in the caption of Fig. 8. Data points of lines with uncertain continuum contributions are shown as lower limits. Mean values are plotted for some lines

beyond the scope of this work. There are, however, two specific aspects that we would like to mention at this stage: (1) There is a systematic difference in the off-limb quiet Sun/coronal holes radiance ratios of lower transition region (TR) lines compared to either chromospheric lines (H I, He II) or the upper TR lines. TR lines with 70 000 K $\leq T_M \leq$ 170 000 K are brighter at heights greater than 5'' to 8'' above the limb over coronal holes. This is in agreement with the findings of Feldman et al. (1976). Some TR lines, as noted above, even exhibit substantially larger limb brightening effects in coronal holes than outside. These coronal hole and quiet Sun observations thus resemble the corresponding radio brightness measurements obtained with the Nobeyama radioheliograph (Gary et al. 1997). (2) The radiance histograms of emission lines in quiet Sun regions appear to follow normal distributions if plotted versus the logarithm of the radiance. This is shown in Fig. 8 for some lines. Moreover, the standard deviations of these distributions exhibit a systematic variation with the formation temperature of the radiation as shown in Fig. 9. The relevant data are compiled in Table 3.

We turn now to the fast sweeps in the He I line which require a special analysis. An area of $3.89 \cdot 10^6$ arcsec² containing the solar disk and corresponding to a solid angle of $9.14 \cdot 10^{-5}$ sr was covered in 920 s. The measurements on KBr (after a background correction of 35 %) gave $4.18 \cdot 10^6$ counts before the rocket launch and $4.20 \cdot 10^6$ counts during the flight, a difference of only 0.5 %. We thus obtain a mean count rate of $4.19 \cdot 10^6/(920 \cdot 295)$ s⁻¹ arcsec⁻² = 15.4 s⁻¹ arcsec⁻² considering that the slit used covered 295 arcsec². This can be converted to a virtual radiance of 330 mW m⁻² sr⁻¹ averaged over the solid angle of the scan area, and an irradiance of $E_{\lambda} = 30.1 \ \mu W m^{-2}$ at SOHO and $30.5 \ \mu W m^{-2}$ at 1 AU (astronomical unit). The solid angle

Date	Line	Wavelength	Width	Remarks ^a
1996		(Å)	(Bin)	
July 04		1404	2 12 ^b	Continuum
July 04		1404	2.15 2.10 ^b	Continuum
Fab 04		1407	2.10	Continuum
Feb. 04		1549	2.04	Continuum
Feb. 04	C: -	1549	2.11	Continuum Eall Sam
June 08	511	1256	1.05	Full Sun
June 14	511	1256	1.62	Full Sun
Feb. 20		804	2.40	Full Sun
July 04		991	2.30°	Continuum
Jan. 30		1031	2.43°	Continuum
July 04	Ly ϵ	937	2.23°	F 11 0
Aug. 11	Ly ϵ	937	2.19	Full Sun
July 04	01	999	2.95	
Mar. 02	HeI	584	2.06	Full Sun
June 26	HeI	584	1.99 ^c	Full Sun
Apr. 29	Fe III	1126	3.56°	28 000 K
Apr. 29	Si IV	1393	3.95°	63 000 K
Apr. 29	Si IV	1402	3.61 ^b	
Jan. 28	CIII	977	3.59	Full Sun
July 04	N III	991	4.44^{b}	80 000 K
Feb. 04	C iv	1548	4.12	Full Sun
Feb. 04	CIV	1548	4.09^{b}	
June 07	CIV	1548	3.08^{c}	Full Sun
June 16	CIV	1548	3.04^{c}	Full Sun
July 04	CIV	1548	4.11^{b}	
Feb. 26	O IV	790	3.42	Full Sun
June 07	O IV	787	2.96^{c}	Full Sun
June 15	O IV	787	2.86^{c}	Full Sun
June 16	O IV	787	2.98^{c}	Full Sun
June 15	S v	786	2.75^{c}	Full Sun
June 08	Νv	1238	2.81 ^c	Full Sun
June 14	Νv	1238	2.71^{c}	Full Sun
May 12	S VI	933	3.65	Full Sun
July 04	S VI	933	3.96^{b}	
June 08	Оv	629	2.62^{c}	Full Sun
June 14	Оv	629	2.64^{c}	Full Sun
Jan. 30	O VI	1031	3.40^{b}	
July 04	Ne VI	999	3.39^{b}	430 000 K
Feb. 02	Ne VIII	770	2.23^{c}	Full Sun
June 07	Ne VIII	770	2.14^{c}	Full Sun
June 16	Ne VIII	770	1.94^{c}	Full Sun
July 04	Ne VIII	770	3.32^{b}	

Table 3. Widths (standard deviation, σ) of the radiance histograms in units of bins (defined in the caption of Fig. 8)

^{*a*} Formation temperatures are given for those lines which are not contained in Table 6

^b Sun centre

^c Lower limit

of the solar disk was $6.73 \cdot 10^{-5}$ sr at the time of observation and thus its mean spectral radiance was $\bar{L}_{\lambda} = 448 \text{ mW m}^{-2} \text{ sr}^{-1}$ in He I (λ 584 Å), which agrees well with the full Sun values in Table 4.

3.2. Radiance spectrum

For comparison with the full disk data and as source of the KBr spectra in Figs. 3 and 4, we present in Fig. 10(a) a radiance spectrum in the wavelength range from 800 Å to 1500 Å in first order obtained on KBr in a quiet Sun region near disk centre on August 12, 1996. The prominent second order lines were manually removed from the measured data, and corrections for detector efficiency variations (gain and dead time) were made, before the sensitivity conversion procedure was applied. The spectrum is only shown up to a wavelength of 1500 Å as the H I Lyman continuum in second order and many weak second order lines produce substantial effects above this limit. A more detailed analysis is needed before a reliable separation can be achieved at longer wavelengths. As was shown above, the second order radiation contributes ≈ 4 % to the observed continuum at 1560 Å. Fig. 10(b) displays the same spectrum in integrated form and illustrates the dominating rôle of H I Ly α in this spectral range.

Despite its compressed presentation, the spectrum in Fig. 10 is plotted with its full spectral resolution. To demonstrate this, two sections are shown in Figs. 11 and 12 on an expanded scale for intervals with multiplets. Fig. 11 displays the O II/O III multiplets near 834 Å and Gaussian fits to the seven lines. Similarly in Fig. 12, the six lines of the CIII multiplet at 1175 Å have been separated, although the weak line at 1175.590 Å close to the strong line at 1175.711 Å could only be estimated. We have also resolved the NII lines near 1085 Å and the HeII Ba γ line and the CII lines at 904 Å. The resulting radiances have been summarized in Table 4 together with some other prominent lines. We can add up the radiances of the multiplets and find $L(OII) = 65.8 \text{ mW m}^{-2} \text{sr}^{-1}$ and L(OIII) =137.7 mW m⁻²sr⁻¹ with L(O II)/L(O III) = 0.48. For L(C II)we obtain 31.6 mW m⁻²sr⁻¹, for *L*(N II) = 75.6 mW m⁻²sr⁻¹, and for $L(C III) = 250 \text{ mW m}^{-2} \text{sr}^{-1}$. The measurements thus obtained are only one way of determining the radiances in the emission lines. Another possibility is to find the quiet Sun level near the solar centre as was done in Figs. 6 and 7. We have added the values in the column " $L_{\lambda}(0)$ " and have taken the mean value if more than one image was available. Also listed is the mean spectral radiance, \bar{L}_{λ} , resulting from the irradiance observation according to Eqs. (10) and (11) and the ratio $\bar{L}_{\lambda}/L_{\lambda}(0)$.

4. Results

4.1. Spectral irradiances

Table 5 gives the irradiance at SOHO for the quiet Sun and the active region and coronal hole contributions. These values were arrived at by integrating the curves presented in Figs. 6 and 7 over the corresponding sectors. For the fast sweep, we only give the full Sun value.

In the previous sections individual uncertainties contributing to the overall uncertainty of the irradiance have been discussed. In addition, we assume a contribution of 0.3 of the amount of the corrections performed on the data to the overall uncertainty. The corrections are listed in Table 2. The column labelled "AR" gives the active region corrections in percent of the

Table 4. Spectral radiances, L_{λ} , for some multiplets and prominent emission lines (without background) of a quiet Sun spectrum obtained on August 12, 1996 near Sun centre. Also given are the $L_{\lambda}(0)$ and \bar{L}_{λ} values of the full Sun observations. (If several images are available, mean values have been entered.) Quiet Sun (QS) radiances available in the literature are listed in the last four columns

Line	Wavelength	Transition	L_{λ}	L_{λ} $L_{\lambda}(0)$ \bar{L}_{λ}		\bar{L}_{λ}	Literature			
	(Å)		(m '	$W m^{-2} sr^{-1}$	-1)	$\overline{L_{\lambda}(0)}$	QS^a	QS^b	\bar{L}^c_{λ}	QS^d
Нет	584.33 ^e	$1s^{2} {}^{1}S_{0} - 1s2p {}^{1}P_{1}$	445	433	437	1.01	429	545		
Оv	629.74 ^e	$2s^{2} {}^{1}S_{0} - 2s2p {}^{1}P_{1}$	271	287	445	1.59	373	335		
Ne VIII	770.41^{f}	$2s^2S_{1/2} - 2p^2P_{3/2}$	79.4	71.1	117	1.64	30.2	53.8		
Sv	786.47^{f}	$3s^{2} {}^{1}S_{0} - 3s3p {}^{1}P_{1}$	29.2	28.0	37.7	1.35				
O IV	787.72^{f}	$2s^22p^2P_{1/2} - 2s^2p^2P_{1/2}$	52.7	48.4	71.7	1.46	65.0	44.4		
0 11	832.762 ^g	$2s^2 2p^3 {}^4S_{3/2} - 2s 2p^4 {}^4P_{1/2}$	2 12.9				blend	blend		
OIII	832.92^{f}	$2s^2 2p^2 {}^3P_0 - 2s 2p^3 {}^3D_1$	13.7				blend	blend		
0 II	833.33 ^{<i>f</i>}	$2s^2 2p^3 {}^4S_{3/2} - 2s 2p^4 {}^4P_{3/2}$	2 21.9				blend	blend		
0 III	833.742 ^g	$2s^2 2p^2 {}^3P_1 - 2s 2p^3 {}^3D_2$	47.3				blend	blend		
0 II	834.45 ^{<i>f</i>}	$2s^2 2p^3 {}^4S_{3/2} - 2s 2p^4 {}^4P_{5/2}$	2 31.0				blend	73.2^{h}		
0111	835.096 ^g	$2s^22p^2 {}^{3}P_2 - 2s2p^3 {}^{3}D_2$	12.9				blend	blend		
0 111	835.26^{f}	$2s^22p^2 {}^3P_2 - 2s2p^3 {}^3D_2$	63.8				152^{h}	75.3^{h}		
CII	903.63^{f}	$2s^22n^2P_{1/2} - 2s2n^2P_{2/2}$	2 5.9				blend	blend		
CII	904.01^{f}	$2s^22n^2P_{1/2} - 2s2n^2P_{1/2}$	2 7.3				blend	blend		
Сп	904 15^{f}	$2s^2 2p^2 P_{2/2} - 2s^2 p^2 P_{2/2}$	2 137				blend	blend		
Сп	904 48 ^f	$2s^2 2n^2 P_{2/2} = 2s^2 n^2 P_{1/2}$	2 13.,				52 2^h	$32 9^h$		
S VI	933 39 ^f	$3s^{2}S_{1/2} = 3n^{2}P_{2/2}$	13.8	15.2	33 5	2 21	19.8	12.9		
HILVE	937 803 ^g	$1s^2S = -6n^2P$	37.7	50.9	59.5 59.1	1 16	667	48.5		
S VI	944 52 f	$3s^2S_{1/2} = -3n^2P_{1/2}$	62	93	19.8	2.13	12.1	96		
HILVA	949 743 ^g	$1s^2S = -5n^2P$	59 1	7.5	17.0	2.15	96.6	7.0		
HILy 0	972 537 ^g	$15^{\circ}S$ $-4n^{\circ}P$	136				190	169		
	977 04^{f}	$2s^{2} S_{0}^{1} S_{0}^{1} - 2s^{2}n^{1}P_{1}^{1}$	702	1064	1672	1 57	1200	963		
HILV B	$1025\ 722^{g}$	$1s^2S - 3n^2P$	766	1004	1072	1.57	728	747		
O VI	1023.722 1031.93^{f}	$2s^2S_{1/2} = -2n^2P_{2/2}$	248				250	305		
CII	1036.34^{f}	$2s^{2}2n^{2}P_{1/2} = 2s^{2}n^{2}S_{1/2}$	35.9				blend	blend		
	1030.94 1037.00^{f}	$2s^2 2p^2 P_{2/2} = 2s^2 p^2 S_{1/2}$	2 33.9 - 44.8				blend	blend ⁱ		
	1037.60^{f}	$28^{2}S_{1/2} = 282P_{1/2}$	118				216^h	$204^{h,i}$		
NII	1083.99^{f}	$2s^{2} 2n^{2} 3P_{2} = 2s^{2} 2n^{3} 3D_{1}$	87				blend	blend		
NII	1083.55 1084.562^{g}	$23 2p 10 = 232p D_1$ $2e^2 2n^2 3 P_1 = 2e^2 2n^3 3 D_1$	blend				blend	blend		
NII	1084.502 1084.60 ^f	$2s^{2}p^{2}^{3}P_{1} = 2s^{2}p^{3}^{3}D_{2}$	20.8^h				blend	blend		
HeII	1084.00 1084.03^{f}	$2s 2p 11 - 2s2p D_2$ $2s^2 S_1 = 5n^2 P_2$	11.2				blend	blend		
NII	1084.93	$23 D_{1/2} = 3p T_{3/2}$ $2e^2 2n^2 B_2 = 2e^2 n^3 B_1$	blend				blend	blend		
NII	1085.527 1085.546^{g}	$23 2p 12 = 232p D_1$ $2e^2 2n^2 3 P_2 = 2e^2 2n^3 3 D_2$	$0 \Lambda^h$				blend	blend		
NII	1085.540 1085.71^{f}	$23 2p 12 = 232p D_2$ $2e^2 2n^2 3 P_2 = 2e^2 2n^3 3 D_2$	2. 4 36.7				$75 \Lambda^h$	$72 7^h$		
CIII	1174.88^{f}	$23 2p 12 = 232p D_3$ $2e2n^3 P_2 = 2n^2 3 P_2$	37.4				hlend	hlend	blend	16.5
Сш	1174.00 1175.24^{f}	$2s_2p \ 1_1 \ -2p \ 1_2$ $2s_2p \ ^3P_2 \ 2n^2 \ ^3P_1$	24.4				blend	blend	blend	10.5
Сш	1175.24° 1175.590^{g}	$2s_2p \ 1_0 \ -2p \ 1_1$ $2s_2p \ ^3P_2 \ 2n^2 \ ^3P_2$	24.4 17.8				blend	blend	blend	19.J blend
Сш	1175.500	$2 s_{2} p_{1} r_{1} - 2 p_{1} r_{1}$ $2 s_{2} n_{2} r_{2} P_{2} - 2 n_{2} r_{2} r_{1}$	104				blend	blend	blend	49.5^h
Сш	1175 08 ^f	$2 s_{2}^{2} p_{1}^{2} p_{1}^{2} - 2p_{1}^{2} p_{1}^{2}$	30.0				blend	blend	blend	10.5
Сш	1176 37 ^f	$2s_{2}p_{1}^{3}P_{2} = 2p_{1}^{2}p_{1}^{3}P_{2}$	36.0				322^h	315^h	280^h	13.5
HILVO	1215.66^{e}	$252p I_2 = 2p I_1$ $1e^2S = 2n^2P$	80500				82 000	64 600	200 71.000	59,000
Nν	1215.00	$2e^{2}S_{1/2} = 2p^{-1}P_{2/2}$	57 A	63 1	131	2.08	85 3	61 /	180	140
Sit	1256.51 ^g	$2s^{2}3n^{2}{}^{3}P_{1} = 2s^{2}n^{3}{}^{3}C_{1}$	20.7	22.9	33.0	2.00	05.5	22.3	100	17
CIV	1548.20^{e}	$1s^22s\ {}^2S_{1/2}\ -1s^22n\ {}^4S_{2/2}$	20.7 2 361	392	869	2.22		22.3	920	196

^{*a*} Dupree et al. (1973) (quiet Sun)

^b Vernazza and Reeves (1978) (quiet Sun, average network)

^c Schmidtke (1984) (\bar{L}_{λ} for quiet conditions) ^d Sandlin et al. (1986) (quiet region)

^e Wavelengths from Feldman et al. (1997)

^{*f*} Wavelengths from Curdt et al. (1997)

^{*g*} Wavelengths from Kelly (1987)

^h Sum of blends

^{*i*} Noci et al. (1987) deduced values of L (C II λ 1037 Å) = 52 and L (O VI λ 1037 Å) = 152.5.



Fig. 10. (a) Quiet Sun spectrum of August 12, 1996 from 01:13 to 03:40 UT in first order from 800 Å to 1500 Å is shown as spectral radiance, L_{λ} , in the lower panel. The pointing of the centre of the slit is given from disk centre (sub-SOHO point) in arcseconds. Some prominent lines are identified with their wavelengths in Ångström and the first order lines (except C IV), for which full Sun images are available, are marked by long ticks. Second order lines are removed from this spectrum. Intervals are indicated, for which resolved lines are included in Table 4. (b) The integrated spectrum is plotted in the upper panel. It is set to zero at 800 Å. The curve is repeated on either side of H I Ly α superelevated by factors of 10 or 5, respectively, and offset by 92 W m⁻²sr⁻¹ at the wavelength of Ly α

measured full Sun values, whereas the coronal hole corrections are provided in the "CH" column. Negative values for "AR" or "CH" mean that the measured full Sun figures were reduced accordingly to obtain the quiet Sun irradiances in Table 5. As explained above, the pixel size variations and the step sizes do not contribute to the overall uncertainty. The detector sampling times are so accurate that their contributions can also be neglected. The uncertainty budgets (1 σ level) for the irradiances are also given in Table 2 with an RMS (root mean square) error propagation. Each raster image contained more than 10⁷ counts and, consequently, statistical uncertainties are very small.

We finally obtain overall relative uncertainties between 15 % and 20 % for most of the lines and a little over 30 % for Si I and C IV. For a comparison with previously published irradiance data at Earth for minimum and more active conditions of the solar cycle, we convert our quiet and full Sun measurements to irradiances at 1 AU, using the mean solar angular radius at 1 AU of 959!'6 (solid angle of solar disk: $6.80 \cdot 10^{-5}$ sr) and the actual angular radii in visible light during the observations. Irradiances of lines measured by SUMER show good repeati-

bility, with relative changes between 1 % and 10 %, which can easily be explained by solar variations. In this respect, quiet Sun irradiance observations reported in the literature over the past two solar cycles vary often by more than this value.

Our Ne VIII values are higher by a factor of 1.2 than earlier quiet and active Sun observations. The SUMER laboratory calibration was particularly complete in this wavelength range (Ne I, 735.9 Å; Ar II, 740.3 Å; Ne I, 743.7 Å; Ar III, 769.2 Å) and thus we are confident that our measurement provides a reliable value for the Ne VIII irradiance during quiet conditions. A major discrepancy is evident for N v, where SUMER finds three times higher values for quiet conditions. Again we see no reason to doubt our radiometric calibration at this wavelength, where a prominent Kr I line was available at 1235.8 Å in the laboratory.

On the other hand, our C IV measurements give results about 40 % smaller than recent literature data. This is outside the uncertainty margin of our assessment, but is probably within the combined error contributions of both measurements.

Table 5. UV and EUV irradiances in emission lines, E_{λ} , for the quiet Sun (QS) at 1 AU, together with the active region contributions Δ (AR) and coronal hole deficiencies Δ (CH) where E_{λ} (QS) + Δ (AR) + Δ (CH) = E_{λ} (FS). A comparison of irradiances obtained in this study for the full Sun (FS) (with relative uncertainties given in Table 2) and in previous work (F_{10.7} \leq 90 and > 90) is made in the last columns

Line	Wavelength	Date			Irradia	nce, E_{λ}	, at 1 AU (μ W m ⁻²)	
	(Å)	1996	QS	$\Delta(AR)$	Δ (CH)	FS	literature: $F_{10.7} \le 90$	> 90
Heı	584.33	Mar. 02	29.3	0.22	-1.19	28.3	27.6 ^{<i>a</i>} ; 34 ^{<i>b</i>} ; 53.7 ^{<i>c</i>}	$30^d; 32^e; 50^f$
He I^g	584.33	June 26				30.5		
Heı	584.33	June 26	28.9	0.97	-1.68	28.2		
Ov	629.74	June 07	31.9	1.84	-0.38	33.4	31.0 ^{<i>a</i>} ; 47.4 ^{<i>c</i>} ;	29^d ; 52^f ; 53^e
Οv	629.74	June 14	31.2	0.90	-0.12	31.9	51^c ; $\approx 55^h$	
Ne VIII	770.41	Feb. 02	8.05	0.02	-0.83	7.24	$6^c; 6.3^c$	5.9^d ; 6.2^e ; 7^f
Ne VIII	770.41	June 07	8.38	0.05	-0.92	7.49		
Ne VIII	770.41	June 16	8.29	0.05	-0.87	7.46		
SV	786.47	June 15	2.60^{i}	0.03	0.04	2.67	3.7 ^c	
OIV	787.72	June 07	5.06	0.12	0.01	5.20	7.0^{c}	$3.3^d; 5^f; 8.2^e$
OIV	787.72	June 15	4.56^{i}	0.02	0.06	4.64		
OIV	787.72	June 16	5.03	0.06	_	5.09		
S VI	933.39	May 12	2.31	0.17	-0.13	2.35	2.1 ^c	2.8^d ; 2.9^e ; 3.3^f
H i Ly ϵ	937.80	Aug. 11	4.00	0.07	-0.10	3.96	4.0^{c}	3.3^{f} ; 4.6^{d} ; 6.1^{e}
S VI	944.52	Aug. 11	1.37	0.02	-0.10	1.29	$1.4^{c}; 3^{c}$	$1.6^f; 1.8^e; 1.9^d$
CIII	977.04	Jan. 28	114^{i}	2.11	1.04	117	80.3 ^{<i>a</i>} ; 88 ^{<i>c</i>} ; 121 ^{<i>c</i>}	90^d ; 93^f ; 140^e
							73^{j} ; 114 ^j ; 124 ^j	
Νv	1238.81	June 07	9.15	0.05	-0.66	8.53	3.1 ^c	6.9^d ; 13^e
Νv	1238.81	June 14	8.92	-	-0.58	8.34		
Si 1	1256.52	June 07	2.25	0.03	-0.01	2.26		
Si 1	1256.52	June 14	2.23	-	_	2.23		
CIV	1548.20	Feb. 04	59.2	0.72	-2.42	57.5	54.4^c ; $\approx 95^h$	
CIV	1548.20	June 07	53.5	1.99	-2.69	52.8		
CIV	1548.20	June 16	55.3	1.37	-2.70	54.0		

^{*a*} Hall et al. (1969) (averaged over five measurements)

^b Lean (1987)

^c Schmidtke et al. (1977); Schmidtke (1984)

^d Hall and Hinteregger (1970)

^e Smith and Gottlieb (1974)

f Heroux et al. (1974)

^g Fast sweep (KBr).

^h Warren et al. (1996)

ⁱ Some portions of the disk (a few %) were not scanned and have been estimated from corresponding sections.

^{*j*} Timothy (1977)

4.2. Spectral radiances

4.2.1. Radiance histograms

The brightness histograms shown in Fig. 8 are interesting in two respects. First, the near-Gaussian distribution for each line is noteworthy. The same behaviour has independently been found with SUMER observations by Griffiths (1997). Second, the width of the histograms as plotted in Fig. 9 exhibit a marked dependence on the formation temperature of the lines with a maximum just below 100 000 K. This means that lines in the central transition region have the largest intensity variations in the spatial regime.

Corresponding studies have been performed on Skylab data by Habbal & Grace (1991). They noted a temperature dependence of the ratio of the spatial density of the variable emission to the enhanced emission with a maximum near 100 000 K. Reeves (1976) demonstrated that near this temperature the network contribution to the quiet Sun radiance has a maximum whereas the cell contribution is at a minimum. It should also be pointed out that the quiet Sun average red shift peaks just above 100 000 K (Doschek et al. 1976b; Chae et al. 1997; Brekke et al. 1997).

4.2.2. Centre-to-limb variations

Quantitative data for the centre-to-limb radiance variations are given in Table 6, as well as values for the solar radius, of the visible limb and for the peak intensities of the corresponding UV and EUV lines.

Table 6. Centre-to-limb variations of UV and EUV emission lines and the temperatures of the maximum ionic abundances, T_M . Positions of quiet Sun (QS) and coronal hole (CH) intensity maxima of the emission lines near the limb. The nominal photospheric radii are listed for the dates of observations

Line	Wavelength	Date	T_M	$L_{\lambda}(\text{limb})/L_{\lambda}(0)$		Radius	Radius Maximum	
	(Å)	1996	(K)	QS	СН	(")	QS	СН
Heı	584.33	Mar. 02	20 000	1.05	0.65	978	970	974
HeI	584.33	June 26	20 000	1.33	0.99	953	946	948
Ov	629.74	June 07	230 000	4.59	4.76	955	965	965
Ov	629.74	June 14	230 000	4.95	5.09	954	963	966
Ne VIII	770.41	Feb. 02	630 000	4.83	2.07	984	990	1002
Ne VIII	770.41	June 07	630 000	5.15	2.02	955	968	970
Ne VIII	770.41	June 16	630 000	4.90	2.09	954	968	971
SV	786.47	June 15	170 000	3.38	5.22	954	961	966
OIV	787.72	June 07	170 000	3.70	4.46	955	963	963
OIV	787.72	June 15	170 000	3.76	5.21	954	961	966
OIV	787.72	June 16	170 000	3.99	4.65	954	962	962
S VI	933.39	May 12	200 000	10.2	8.92	959	965	955
H i Ly ϵ	937.80	Aug. 11	10 000	1.74	1.38	956	954	954
S VI	944.52	Aug. 11	200 000	10.1	7.75	956	964	960
CIII	977.04	Jan. 28	70 000	3.25	3.49	984	985	991
Νv	1238.81	June 07	180 000	15.6	11.1	955	959	959
Νv	1238.81	June 14	180 000	18.6	11.2	954	960	958
Siı	1256.52	June 07	10 000	4.64	4.76	955	954	950
Siı	1256.52	June 14	10 000	5.10	4.83	954	954	954
CIV	1548.20	Feb. 04	100 000	10.8	8.05	983	984	990
CIV	1548.20	June 07	100 000	10.5	7.38	955	962	958
CIV	1548.20	June 16	100 000	12.8	8.77	954	960	959



Fig. 11. Spectral radiance of the O II/O III multiplets near 834 Å with Gaussian fits (shown in dotted and dashed lines with the resolution of the data points). The literature wavelengths are taken from Kelly (1987) and Curdt et al. (1997)

The scan range in the heliospheric east-west spatial dimension was verified with a relative uncertainty of 0.4 % (1 σ) with the SUMER RSC in visible light. Near the limb the determination of the position with respect to the centre of the disk should be accurate to within a few arcseconds.



Fig. 12. Spectral radiance of the C III multiplet at 1175 Å with Gaussian fits. The literature wavelengths are taken from Kelly (1987)

As can be seen, the lines behave quite differently with their formation temperatures, T_M , (cf., Arnaud & Rothenflug 1985) and, for some of them also inside and outside coronal holes. For all lines where a comparison is possible our results agree with those obtained by Doschek et al. (1976a) and Feldman et al. (1976). The Ne VIII line (see also Fig. 2) has very low intensities near disk centre which do not seem to represent quiet Sun conditions. We thus provide the centre-to-limb ratio in relation



Fig. 13. Contributions to the uncertainty budget by the count statistics. Three typical SUMER sampling modes are displayed for reference spectra of quiet Sun regions on the KBr photocathode. From top to bottom are shown: (a) Single spatial pixel data of 1" slit obtained with a sampling time of 300 s. (b) 120 spatial pixel sum along the short 1" slit and a sampling time of 100 s. (c) 300 spatial pixel sum along the long 1" slit and a sampling time of 300 s. The Lyman α attenuator and the bare MCP, which can only be used in the spectral range near Ly α , reduce the H I Ly α count rates by a factor of 10 each and thus lead to an increase in the statistical uncertainty for Ly α of 10. In the context of this work, the middle curve is relevant for the radiance measurements

to a quiet Sun region some distance away from the centre of the disk. The other Ne VIII rasters also show such effects with areas of depressed emission near Sun centre.

The fall-offs of the intensities in the corona are affected by the presence of macrospicules and prominences, in particular for the C IV line in the quiet Sun sectors. Off-limb stray-light effects should be very small at heights below 30" as can be seen from the steep gradients near ≈ 20 " in the O IV and N V lines, but have not been studied in this communication. For detailed investigations of the behaviour of emission lines near the limb, full Sun integrations are not the best data base and measurements along a radius vector should be used as has been demonstrated in Sect. 3.1.

If the centre-to-limb variation is of the type $L_{\lambda}(\vartheta)$ and is known, the mean spectral radiance, \bar{L}_{λ} , and the spectral irradiance, E_{λ} , (at the Earth) can be determined from $L_{\lambda}(\vartheta_o)$ measurements anywhere on the quiet Sun. In our case, these conditions are valid for O V, C III, and Si I. They are approximately fulfilled for S V, O IV, S VI, and C IV and thus observations on the disk (e.g., at disk centre or at the limb) should provide, estimates for the total radiation in the lines using Eqs. (7), (10), and (11).

Integration of Eq. (7) with $\rho_{\lambda}(\vartheta) = 1/\cos\vartheta$ yields

 $\bar{L}_{\lambda} = 2L_{\lambda}(0) \tag{12}$

and with
$$\rho_{\lambda}(\vartheta) = 1$$
 we get

$$\bar{L}_{\lambda} = L_{\lambda}(0) \tag{13}$$

As can be seen from Fig. 6, the centre-to-limb variation of the S VI, N V, and C IV lines can be approximated by a $f(\vartheta_{\rm UV}) = 1/\cos \vartheta_{\rm UV}$ function from disk centre to close to the limb. This dependence is obtained under the assumption of an emission layer of constant thickness and optically thin regions. Consequently we would expect Eq. (12) to be approximately fulfilled for these lines. By consulting Table 4 it can be verified that this is indeed the case. The lines stemming from optically thick regions (He I and H I Ly ϵ) have values of $\bar{L}_{\lambda}/L_{\lambda}(0)$ slightly above one, whereas the other lines range from 1.35 (S V) to 1.63 (Ne VIII).

4.2.3. Radiance spectrum

The uncertainty budget for the irradiance values has been shown in Table 2. The same budget is also relevant in the context of the spectral radiance evaluation, but with the addition of the uncertainty of the actual pixel size, if only selected portions of a slit will be taken into account. A typical uncertainty in pixel size is 10 %, but this value can be reduced for specific pixel locations by a detailed geometric evaluation. Weak lines may also suffer from uncertainties introduced by the count statistics. This is illustrated in Fig. 13 where the statistical uncertainties for three typical sampling modes are shown. Even in single pixel mode most of the bright lines have, however, uncertainties of less than 5 %.

A much more serious complication is the definition of a quiet Sun radiance spectum. For lines, such as C III or C IV, we find cell to network ratios of ≈ 0.3 . See also Reeves (1976) and the variability studies by Habbal and Grace (1991). Consequently, the observations, if integrated along the slit, critically depend on the exact distribution of cell and network areas covered by the slit. Even if large areas of the quiet Sun were sampled over extended periods of time, as was done for the SOHO intercalibration measurements, variations of up to \pm 30 % were observed, while the long-term average was constant. For instance, radiances between $L_{\lambda} = 310 \text{ mW m}^{-2} \text{ sr}^{-1}$ and 510 mW $m^{-2} sr^{-1}$ were observed for He I and values between $L_{\lambda} = 40 \text{ mW m}^{-2} \text{ sr}^{-1}$ and 75 mW m⁻² sr⁻¹ for Ne VIII (Hollandt et al. 1997; Schühle et al. 1998). The separation of the spectra in cell and network portions would be a first step towards a better definition. This is, however, beyond the scope of this contribution aimed at the evaluation of the full Sun images.

Given this complication, a comparison with literature data is not easy. Nevertheless, we have listed in Table 4 relevant radiance observations from different sources. Whenever a direct comparison can be made, we find agreement within the uncertainty margins. The radiances of unresolved lines are included in the values of the long-wavelength members of the corresponding multiplets. It should be noted, however, that the values in the last column (Sandlin et al. 1986) have been computed from peak intensities and line width information and that the data by Schmidtke (1984) represent \bar{L}_{λ} values.

All SUMER data analysed here are available for further studies in the public domain of the SOHO archive.

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References

- Arnaud M., Rothenflug R., 1985, A&AS 60, 425
- Brekke P., 1993, ApJS 87, 443
- Brekke P., Hassler D.M., Wilhelm K., 1997, Solar Phys. 175, 349
- Brueckner G.E., et al., 1993, J. Geophys. Res. 98, 10695
- Chae J., Yun H.S., Poland A.I., 1998, ApJS 114, 151
- Chandra S., Lean J.L., White O.R., Prinz D.K., Rottman G.J., Brueckner G.E., 1995, Geophys. Res. Lett. 22, 2481
- Curdt W., Feldman U., Laming J.M., Wilhelm K., Schühle U., Lemaire P., 1997, A&AS 126, 281
- Doschek G.A., Feldman U., VanHoosier M.E., Bartoe J.-D.F., 1976a, ApJS 31, 417
- Doschek G.A., Feldman U., Bohlin J.D., 1976b, ApJ 205, L177
- Dupree A.K., Huber M.C.E., Noyes R.W., Parkinson W.H., Reeves E.M., Withbroe G.L., 1973, ApJ 182, 321
- Feldman U., Doschek G.A., VanHoosier M.E., Purcell J.D., 1976, ApJS 31, 445

- Feldman U., Behring W.E., Curdt W., Schühle U., Wilhelm K., Lemaire P., 1997, ApJS 113, 195
- Gary D.E., Enome S., Shibasaki K., Gurman J.B., Shine R.A., 1997, (Proc. AAS-STD Meeting, Bozeman, MT, June 1997), BAAS 29, p. 912
- Griffiths, N.W., 1997, private communication
- Habbal S.R., Grace E., 1991, ApJ 382, 667
- Hall L.A., Higgins J.E., Chagnon C.W., H.E., 1969, J. Geophys. Res. 74, 4181
- Hall L.A., Hinteregger H.E., 1970, J. Geophys. Res. 75, 6959
- Heroux L., Cohen M., Higgins J.E., 1974, J. Geophys. Res. 79, 5237
- Hinteregger H.E., 1970, Ann. Geophys. 26, 547
- Hinteregger H.E., 1977, Geophys. Res. Lett. 4, 231
- Hollandt J., Schühle U., Paustian W., Curdt W., Kühne M., Wende B., Wilhelm K., 1996, Appl. Opt. 35, 5125
- Hollandt J., Curdt W., Schühle U., Wilhelm K., 1997, Phys. Blätter 53, 1101
- Hovestadt D., et al., 1995, Solar Phys. 162, 441
- Judge D.L., et al., 1998, Solar Phys. 177, 161
- Kelly R.L., 1987, J. Phys. Chem. Ref. Data 16, 1
- Kjeldseth Moe O., Nicolas K.R., 1977, ApJ 211, 579
- Lean J.L., 1987, J. Geophys. Res. 92, 839
- Lean J.L., Repoff T.P., 1987, J. Geophys. Res. 92, 5555
- Lean J.L., 1991, Rev. Geophys. 29, 505
- Lean J.L., Mariska J.T., Strong K.T., Hudson H.S., Acton L.W., Rottman G.J., Woods T.N., Willson R.C., 1995, Geophys. Res. Lett. 22, 655
- Lemaire P., et al., 1997, Solar Phys. 170, 105
- Mango S.A., Bohlin J.D., Glackin D.L., Linsky J.L., 1978, ApJ 220, 683
- Mariska J.T., Feldman U., Doschek G.A., 1978, ApJ 226, 698
- Noci G., Kohl J.L., Withbroe G.L., 1987, Astrophys. J. 315, 706
- Reeves E.M., 1976, Solar Phys. 46, 53
- Rottman G.J., 1988. Adv. Space Res. 8, (7)53
- Rottman G.J., Woods T.N., Sparn T.P., 1993, J. Geophys. Res. 98, 10667
- Sandlin G.D., Bartoe J.-D.F., Brueckner G.E., Tousey R., VanHoosier M.E., 1986, ApJS 61, 801
- Schmidtke G., Rawer K., Botzek H., Norbert D., Holzer K., 1977, J. Geophys. Res. 82, 2423
- Schmidtke G., 1981, Solar Phys. 74, 251
- Schmidtke G., 1984, Modelling of the solar extreme ultraviolet irradiance for aeronomic applications. In: Flügge, S., Rawer, K. (eds.) Handbuch der Physik, XLIX/7, Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, p. 1
- Schühle U., Brekke P., Curdt W., Hollandt J., Lemaire P., Wilhelm K., 1998, Appl. Opt., in press

Smith E.V.P., Gottlieb D.M., 1974, Space Sci. Rev. 16, 771

- Timothy J.G., 1977, The solar spectrum between 300 and 1200 Å. In: White O.R. (ed.) The Solar Output and its Variation. Colorado Associated University Press, Boulder, p. 237
- Unsöld A., Baschek B., 1991, Der neue Kosmos. Springer-Verlag, Berlin, Heidelberg, New York
- Vernazza J.E., Reeves E.M., 1978, ApJS 37, 485
- Warren H.P., Mariska J.T., Lean J.L., Marquette W., Johannesson A., 1996, Geophys. Res. Lett. 23, 2207
- Watanabe K., Hinteregger H.E., 1962, J. Geophys. Res. 67, 999
- Wilhelm K., et al., 1995, Solar Phys. 162, 189
- Wilhelm K., et al., 1997a, Solar Phys. 170, 75
- Wilhelm K., Lemaire P., Feldman U., Hollandt J., Schühle U., Curdt W., 1997b, Appl. Opt. 36, 6416
- Withbroe G.L., 1970a, Solar Phys. 11, 42
- Withbroe G.L., 1970b, Solar Phys. 11, 208
- Woods T.N., et al., 1996, J. Geophys. Res. 101, 9541