THE EUV SPECTRAL IRRADIANCE AND THE PHYSICAL CHARACTERISTICS OF THE SOLAR CORONA DURING THE 10 YEARS OF SOHO MEASUREMENTS.

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ABSTRACT

The SOHO instruments have performed extremely well and provided us for the first time detailed measurements in the EUVs, from solar minimum (1996) through the maximum (2001-2002) and up to now. These measurements enable us to describe the characteristics and long-term variations of the EUV spectral irradiance and overall of the solar corona. First, we present EUV (150-800 A) radiance measurements obtained with the SOHO/Coronal Diagnostic Spectrometer - Normal Incidence (NIS) and Grazing Incidence (GIS) from 1996 to now. Then we discuss the evolution (from minimum to maximum) of the physical and morphological characteristics of the solar corona that we can infer from the spectra. We discuss the contribution of active regions to the entire corona and the total EUV irradiance during maximum. We complement the CDS measurements with SOHO/EIT images, discuss the center-to-limb variations, and obtain irradiance measurements in the lines observed by CDS. These are the first long-term continuous measurements of the solar EUV spectral irradiance. We compare the results with the TIMED measurements and with the previous ‘historical’ ones, mostly made in the 1970s. A discussion of the CDS calibration and cross-calibration of the instruments on board SOHO (CDS,EIT,SEM) is presented.

1. INTRODUCTION

The solar irradiance is one of the main drivers for global climate. However, many of the physical processes behind the Sun-Climate connection, remain unclear. Variability of the total solar irradiance exists but is small (0.2\%) and insufficient to explain the variations on the global climate. Variations in the UV are however more considerable (cf. Woods et al. 2005 and/or references therein). Solar variability is known to increase toward the EUV and X-rays, but the details, in particular of its spectral distribution, are not known.

The EUV radiation creates the ionosphere and might also have an indirect effect on the climate. Only EUV radiation is able to photoionise important neutrals such as N, O and important molecules such as N\textsubscript{2}. Very few EUV observations exist, until the launch of TIMED in 2002 (cf. Woods et al. 2005). It has therefore become customary to simply model the EUV irradiance by using proxies of the solar activity. However, large uncertainties in the models exist, due to the fact that it is not known how well proxies that are good to represent the UVs are also good to model EUVs.

SOHO gives us the first opportunity to study EUV irradiances along a full solar cycle, from 1996 (minimum) to now. Also, it allows to perform measurements of the irradiances of the different solar regions. Accurate measurements are not trivial, and depend on a stable radiometric calibration, which is a difficult issue in the EUVs. An important by-product of this work is a check on the consistency of the cross-calibration between the different SOHO instruments. After two workshops held at ISSI (cf. Del Zanna, 2002, and the book ‘The radiometric calibration of SOHO’), the various teams have converged to a consistent relative radiometric calibration between the various instruments within 30-50\%, but only for the first years of the mission, and at few selected wavelengths. Large uncertainties in the long-term ageing of each of the SOHO instruments are still present and a lot of work is in progress. Corrections for instrument ageing need to be applied to all SOHO data, and have become large.

We present here a summary of some of the results obtained. Ours is a long-term research plan which aims at addressing the following open questions:

-What are the characteristics of the EUV irradiance and in general of the solar corona?
-What are their long-term variations?
-Is the ‘quiet’ Sun constant in time?
-What is the relation between EUV irradiance and magnetic activity?
-How much is the contribution to the total irradiance from active regions?
-Can we use indices of activity to model the EUV irradiance?
-Does the EUV irradiance affect the global climate?
2. SOHO/CDS NIS MEASUREMENTS

The SOHO/Coronal Diagnostic Spectrometer (CDS), composed of a Normal Incidence (NIS) and a Grazing Incidence (GIS) Spectrometer, covers, with a few minor gaps and 9 channels, the important 150-800 Å EUV spectral range.

The CDS instrument has obtained various types of routine radiance measurements over the years, with both spectrometers. With the NIS, routine measurements over the quiet Sun, and daily synoptic observations of the meridian have been taken. We have processed the synoptic observations and studied, for the first time, the evolution of the spectral line intensity distributions along a cycle. At lower temperatures (He I, O V) these distributions, over quiet regions, appear remarkably stable and have a log-normal distribution.

Also, about once a month, ‘sparse’ observations covering the full-Sun have been taken. They consist of 700-1000 single slit exposures sampling the whole Sun in about 13 hours (1998-2005). See Thompson & Brekke (2000) for details. We have developed special processing techniques to analyse a selection of these full-Sun spectra, and to obtain from them a mosaic of the radiances of the whole Sun in all the NIS lines. We chose observations when the Sun was quiet. Sample monochromatic images in a few lines are shown in Figures 1,2. They clearly show the effect of the presence of the active regions on the disk and off-limb radiances, in particular for the hotter lines over the solar cycle. We have used these data to study the center-to-limb behaviour at all temperatures, and to obtain radiances in each of the lines. A sample is shown in Figure 3. The cooler transition region lines show a small variation with activity cycle, while the hotter coronal lines present more considerable variations. The ab-
solute values are in broad agreement with the 'historical' measurements (mostly from rocket spectrometers) done in the 1960s and 1970s.

However much uncertainty is present, and is mostly due to the CDS radiometric calibration and its variations from 1996 to now. The 'standard' CDS calibration available through SolarSoft is based on a comparison between the EGS rocket flight of 1997/05/15 (Woods Rocket) and CDS/NIS FULL SUN NIS spectral radiance measurements. It is described in (Brekke et al. 2000).

The Del Zanna et al. (2001) radiometric calibration was obtained relative to the value at 584 Å. Once the same responsivity at 584 Å is used, the scaled Del Zanna et al. (2001) and the 'standard' calibrations agree within 30% or so, which is satisfactory.

The use of the wide slit (number 6) causes with time a drop in the NIS sensitivity. A correction to the strongest line, the He I 584 Å, has been obtained by W.T.Thompson by analysing the long-term synoptic data, and assuming that in quiet Sun regions the He I 584 Å radiance should be constant with time. Basically, the corrections to the other wavelengths have been estimated by adopting average solar spectra and scaling the gain losses at 584 Å to the other wavelengths. The corrections have become large (factors of 2-3) for the stronger lines.

The only direct way to assess the evolution of the radiometric calibration is to use rocket flights. Unfortunately, after 1997, only a few rocket flights are of some use. The best ones are the EGS rocket flights flown, in 2002,2003, and 2004, as part of the program to calibrate the TIMED/SEE spectrometers. Their spectral resolution is much worse than NIS, but the entire NIS channels are covered. The TIMED/SEE spectral irradiances have been indeed calibrated in this way. We have performed preliminary comparisons between the CDS and calibrated TIMED/SEE spectral irradiances, and found indications for the need to revise the radiometric calibration of the CDS/NIS. More details will soon be published.

3. SOHO/CDS GIS AND EIT MEASUREMENTS

We have also analysed the synoptic GIS observations of the quiet Sun. They mostly consist of 30" × 30" raster scans, performed routinely with the exception of the period of the temporary loss of contact with SOHO (in 1998), and in 2002, when the GIS rastering was discontinued. We used simultaneous SOHO/EIT broad-band images of the Sun centred at 171, 195, 284 and 304 Å to estimate the limb-brightening and infer irradiances for the 'quiet' period 1996-1998. These compare very well with the few measurements done during 'quiet' periods in the 60's and 70's.

We also studied the distribution of the various solar regions using the EIT images. We have found how the different regions on the Sun contribute differently over the cycle in terms of e.g. fractional area of the disk and histograms, as shown in Fig. 5.

4. CONCLUSIONS

The SOHO instruments have produced a large amount of valuable data in the EUV domain. The GIS, despite a degradation due to the 1998 SOHO loss, has performed extremely well, from 1996 until now. The NIS calibration has also been very stable, with the main degradation due to the use of the wide slit. We have found the need to revise the currently-available calibrations for both the GIS and the NIS. Work is in progress to characterise the CDS/EIT cross-calibration and the absolute CDS calibration.

SOHO/CDS measurements indicate a clear increase in the irradiances of the 'quiet Sun' at all temperatures during higher solar activity. This increase is more pronounced in lines formed just above a million (1 MK) degrees. The 'quiet Sun' is clearly identifiable only during solar minimum. However, the intensity distribution in lines formed below 1 MK is remarkably stable. During increased solar activity, the entire diffuse 'quiet' solar corona shows a different intensity distribution and spectral characteristics, being affected by the presence of the active regions.

The EUV irradiances obtained from CDS are in relatively good agreement with the few historical records and with
Figure 5. EIT images (corrected for limb-brightening; same intensity scaling) in the 284 Å band. The boxes close to Sun centre show the positions of the GIS rasters. The corresponding histograms are also shown.

Figure 6. Observed SOHO/GIS calibrated radiiances (left panels) with superimposed (normalised) SOHO/EIT effective areas, and the expected SOHO/EIT count rate spectra (right panels), in 1996 (minimum) and 2002 (maximum). Notice the large contribution from Fe XI 189 Å to this band, compared to the Fe XII lines.

Figure 7. Same as the previous Figure. Note that in solar minimum conditions the Fe XV 284 Å line is virtually absent, while it becomes dominant during maximum.

ACKNOWLEDGMENTS

GDZ acknowledges support from PPARC.

We thank our colleagues, in particular T. Woods and W.T. Thompson, for useful discussions. We also thank P. Brekke and W.T. Thompson for starting the full-Sun CDS program.

REFERENCES