

The EUV spectral irradiance of the Sun from 1997 to date

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Abstract. We present measurements of the EUV spectral irradiance we have obtained from radiance measurements with the SOHO Coronal Diagnostic Spectrometer, from 1997 to date. We discuss the contribution of the various regions of the Sun to the total EUV irradiance, and how they varied dramatically between the last two solar minima. These observations allow us to interpret spectral irradiance measurements in the EUV which have been available since 2002 with the TIMED mission. We also briefly discuss how changes in various activity indices compare with the EUV spectral variability, and the limitations of spectral modelling.

Keywords. Sun: UV radiation, Sun: activity, solar-terrestrial relations

1. Introduction

The importance of studying the EUV solar irradiance is twofold: the study of the Sun-as-a-star, as a key to interpret EUV emission from similar stars, and the effect of the solar EUV radiation on the Earth system. The study of the EUV solar irradiance is in fact the study of the emission from a star for which we also have detailed information about the distribution of the sources on its surface. Thus far, studies in this direction have been carried out only in the X-ray range using broad-band filter observations (e.g. Orlando *et al.* (2004)). Some effects of the EUV radiation on Earth's atmosphere – particularly on the thermosphere – are well known. More subtle effects on the Earth system, perhaps on the climate, are currently debated. Some recent results (Meehl *et al.* (2009)) seem to hint that even the very small amount of variation along the activity cycle of the solar energy output (of the order of 0.1%) can produce significant effects on some local climate patterns. The FUV and EUV radiation, although only a small fraction of the total solar output, display variations of much larger amplitude as the magnetic activity of the Sun varies across its 11-year cycle. Whether and how such large variations can produce some effect – however small – on Earth's climate is still unclear (Lean *et al.* (1995), Haigh (1996), Priest *et al.* (2007), Foukal *et al.* (2009)).

2. Measurements of the EUV spectral irradiance

Despite the importance of the EUV solar irradiance, few measurements are actually available, and those few either are taken from sounding rockets, and thus give only a snapshot of the solar irradiance, or cover less than one solar cycle. Data from the NASA TIMED SEE experiment (Woods *et al.* (2005)), for instance, cover the solar cycle only since 2002. Therefore, all studies on the solar irradiance and its effects, for example, on the Earth's atmosphere are based on proxies. Such an approach, of course, adds an

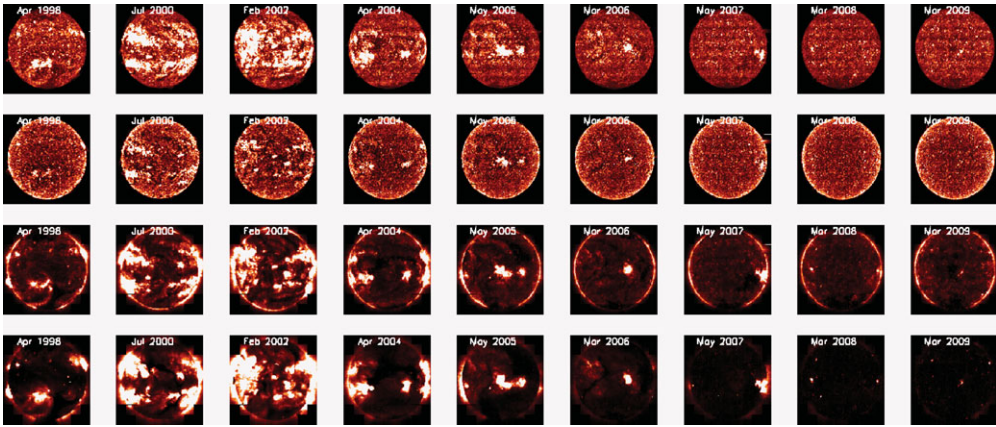


Figure 1. CDS radiances from (top from bottom) He I, O v (~ 0.25 MK), Mg X (~ 1 MK), Fe XVI (~ 2.5 MK), from the beginning of cycle 23, to the current extended minimum.

additional layer of complexity and uncertainty to those studies. Hence the need for direct, reliable measurement of the solar EUV, spectrally resolved irradiance.

SOHO has been observing the Sun since 1996. Apart from the broad-band measurements of CELIAS/SEM (Hovestadt *et al.* (1995)), the Coronal Diagnostics Spectrometer (CDS; Harrison *et al.* (1995)), has been observing routinely the full solar disc in the ranges 31–38 and 51.5–63 nm with its *Normal Incidence Spectrograph* (NIS). We have thoroughly re-examined the performance and radiometric calibration of the NIS instrument, and found that, in fact, it has performed exceptionally well, with a sensitivity loss by only a factor of 2 across all wavelengths in 13 years of operations (Del Zanna *et al.* (2009)). In particular, we checked our results against those of the prototype of the NASA SDO EUV irradiance monitor (EVE), launched in April 2008 (Woods *et al.* (2009), Chamberlin *et al.* (2009)), and found agreement in the radiometric calibration within 30%. Discrepancies were instead found with the TIMED/SEE irradiances (version #9).

The CDS/NIS irradiances we computed were derived from mosaics of spectrally-resolved radiance measurements taken in average once a month with the CDS study USUN, comprising ~ 1000 exposures (spectra) sampling the whole Sun in about 13 hours (Fig. 1). The strongest, unblended lines in the spectra were extracted, and their integrated radiance computed. Estimates of the contribution of off-limb radiance were also made. The resulting irradiances in a selection of EUV lines are shown in Fig. 2, with the values obtained from the EVE prototype (diamonds) and those from the CDS/ rocket EGS measurements of May 1997 by Brekke *et al.* (2000) [asterisks].

3. Conclusions and future work

From the analysis of the CDS irradiances (and of historical measurements from the 60's), we found that lines formed in the low transition region show relatively modest changes (up to 50%). Lines forming around 1 MK already change during the cycle by a factor ~ 5 ; for hotter lines (2.5 MK) the variability reaches factors of the order of 40. The presence of active regions during the solar cycle has a strong influence even in regions of the more “quiet corona” which change considerably along the cycle. Furthermore, we started investigating the reliability of various proxies of solar EUV irradiance. As expected, we are finding that it is virtually impossible to predict solar EUV irradiances

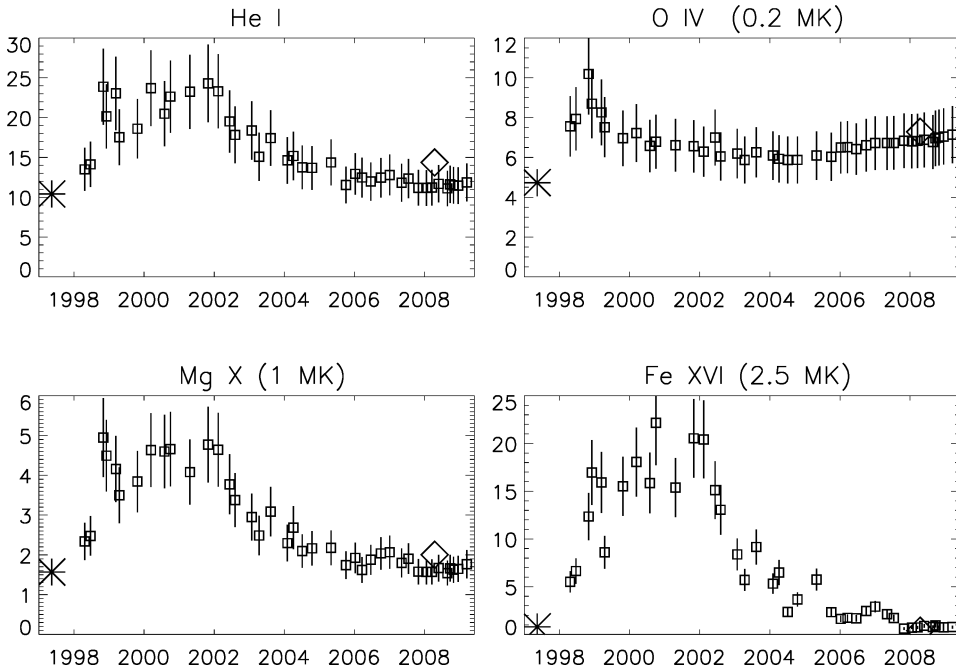


Figure 2. CDS spectral irradiances (boxes) compared with SDO/EVE prototype spectrum.

based on any proxy variation. Moreover, even if a proxy or a set of proxies were found to be sufficiently reliable to reproduce the solar irradiance at some EUV wavelength or band, translating such a result to the analysis of the EUV emission of other stars is very dangerous: for example the spot-to-plage ratio likely depends on the stellar activity level. Future work will focus on improving models of the solar EUV irradiance, with the goal of providing reliable input to climate models and to models of the effects of the magnetic activity of young stars (including the young Sun) on planets.

Acknowledgements

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References

- Brekke, P., Thompson, W. T., Woods, T. N., & Eparvier, F. G. 2000, *ApJ*, 536, 959
 Chamberlin, P. C., Woods, T. N., Crotser, D. A., *et al.* 2009, *GRL*, 36, 5102
 Del Zanna, G., Andretta, V., Chamberlin, P. C., *et al.* 2009, *A&A*, accepted
 Foukal, P., Bertello, L., Livingston, W. C., *et al.* 2009, *Solar Phys.*, 255, 229
 Haigh, J. D. 1996, *Science*, 272, 981
 Harrison, R. A., Sawyer, E. C., Carter, M. K., *et al.* 1995, *Solar Phys.*, 162, 233
 Hovestadt, D., Hilchenbach, M., Bürgi, A., *et al.* 1995, *Solar Phys.*, 162, 441
 Lean, J., Beer, J., & Bradley, R. 1995, *GRL*, 22, 3195
 Meehl, G. A., Arblaster, J. M., Matthes, K., Sassi, F., & van Loon, H. 2009, *Science*, 325, 1114
 Orlando, S., Peres, G., & Reale, F. 2004, *A&A*, 424, 677
 Priest, E., Lockwood, M., Solanki, S., Wolfendale, A., & Coustenis, A. 2007, *A&G*, 48, 03
 Woods, T. N., Chamberlin, P. C., Harder, J. W., *et al.* 2009, *GRL*, 36, 1101
 Woods, T. N., Eparvier, F. G., Bailey, S. M., *et al.* 2005, *JGR (Space Physics)*, 110, 1312