GLOBAL ASYMMETRY OF THE SUN OBSERVED IN THE EXTREME ULTRAVIOLET RADIATION

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ABSTRACT

We report on the observations of the solar luminosity variations in four SOHO/EIT bandpasses over the period 1996 – 2001. Contributions of coronal holes, intermediate brightness features, active regions and bright points are evaluated. We find that during the epoch of low activity a significant contribution to the longitudinal asymmetry, and thus to the 27-day variability of the solar EUV radiation, is produced by the numerous intermediate brightness elements that are globally distributed over large areas (up to 2/3 of the whole surface of the Sun) and generally correspond to the "quiet Sun". During the activity minimum the contribution of this component is comparable to the active regions contribution. The "quiet Sun" average brightness exhibits rotational modulation throughout half of the solar cycle observed by SOHO.

Key words: Sun: EUV radiation; irradiance; EIT.

1. INTRODUCTION

Identifying the solar phenomena responsible for the luminosity variations of the Sun in various spectral domains is now a key issue in solar physics, with implications on Sun–Earth relations. These luminosity variations are associated with a wide variety of solar phenomena: sunspots, active regions, faculae and plages, bright points, granulation and the supergranulation network, and a non-uniform, filamentary distribution of emission excess outside active regions. However, the data series are scarce, and integrated flux measurements do not allow to distinguish unambiguously the respective contributions of the various solar structures (Willson & Hudson, 1991; Foukal & Lean, 1986; Fligge et al., 1998; Ogawa et al., 1998). Solar cycle variations and periodicity of about 27 days related to the rotation of the Sun have been well observed in the solar X-ray and extreme ultraviolet (EUV) radiation for a long time (Rottman, 1983). A composite record of the Sun's total irradiance also exhibits a prominent 11-year cycle, as well as solar rotation modulation effects (Fröhlich et al., 1997).

Multi-scale dynamical structures are permanently present on the Sun and contribute to the variations of the electromagnetic radiation in different spectral ranges. Morphological situations are traditionally characterized as 'quiet' and 'active' in this respect. Three-component models of the solar radiation include structureless quiet Sun and the contributions of active regions and coronal holes (Warren et al., 2001), taking into account the areas of different components and their average contrast. However, the "quiet Sun" component consists of low-contrast inhomogeneities, which are difficult to measure with enough accuracy, especially over long durations.

In this study, we investigate the contribution of these three components to the asymmetry of the solar UV radiation during the observed part of the current 23rd solar cycle. In general, our analysis extends the investigations reported by Veselovsky et al. (2001), now taking into account the long-term calibration of the EIT.

2. DATA ANALYSIS

We extracted a specific SOHO/EIT data subset: one full-resolution image (1024×1024 pixels) per day was selected in all four EIT bandpasses. The resulting image set runs from January 1996 to February 2001. These images were corrected for the grid and CCD flat-field artefacts (Moses et al., 1997), as well as for the long-term aging effects, see Clette et al. (2002) and full description by Newmark et al. (2002). The results of our calculations are presented in Figure 1, where the integral disc-plus-limb intensity variations in four EIT lines are plotted. A coherent periodic modulation is clearly seen in all four data sets, with the 27-day period of the solar rotation, which indicates that a significant longitudinal asymmetry of the solar EUV radiation is present.

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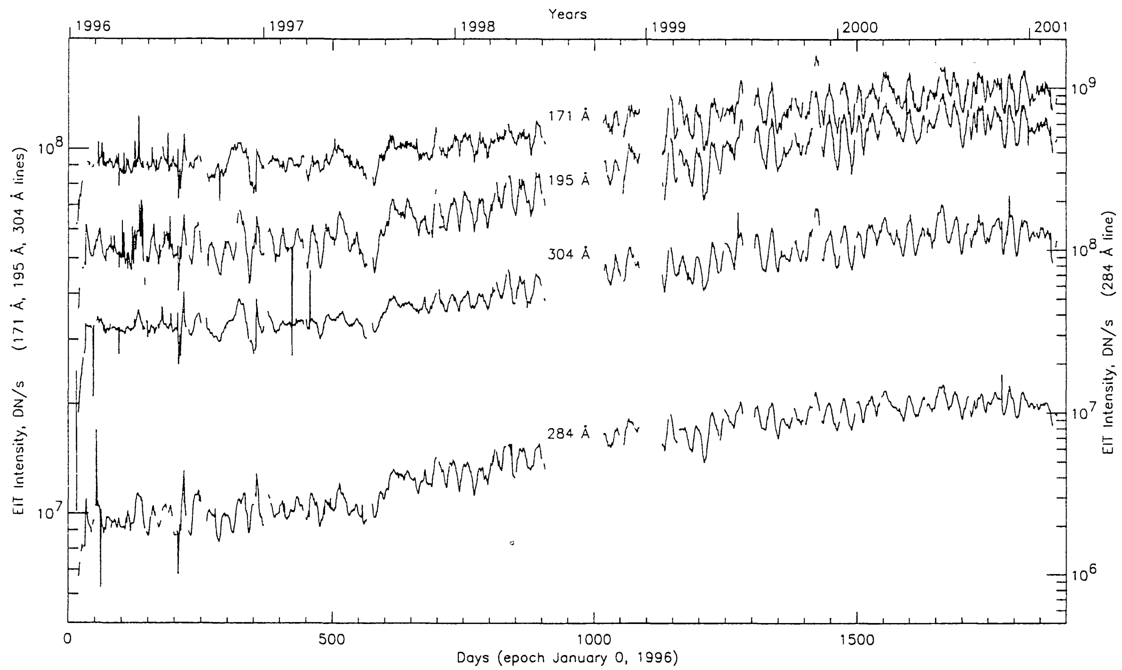

Figure 1. Integral disc-plus-limb intensity variations of the solar emission recorded by SOHO/EIT in the Fe IX/X (171 Å), Fe XII (195 Å), He II (304 Å) and Fe XV (284 Å) lines. Each point on the curves represents the integral of the count rates (digital numbers, DN) per second over the whole field of view in the corresponding bandpass. The relative contribution of the disc to the total intensity depends on the wavelength and is about 2–15 times larger than the limb contribution.

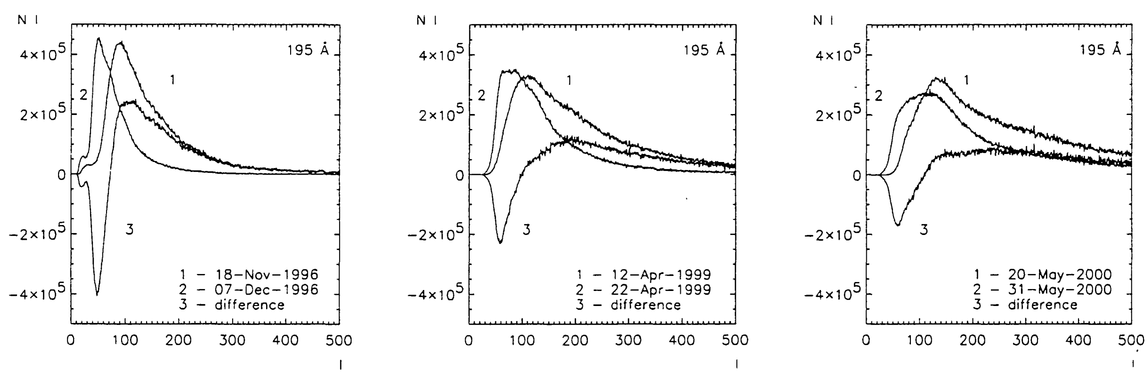

Figure 2. Statistical distributions of the on-disc pixels for the EIT images in the Fe XII line for different phases of the solar activity cycle: minimum (left panel), rising phase (middle panel), maximum (right panel). The dominant intensity range 0–10000 DN/s (in raw units of EIT digital numbers, DN/s) was divided into bins of $\Delta I = 1$ DN/s, and the partial intensity NI contained in each bin was calculated (where N is the number of pixels in a bin of given intensity I). Curve 1 on each panel represents the distribution for the brightest image during a rotation, curve 2 – for the darkest one, curve 3 shows the difference between the curves 1 and 2. The axes are graduated in DN/s. The histograms for the other three EIT bandpasses have similar shape.

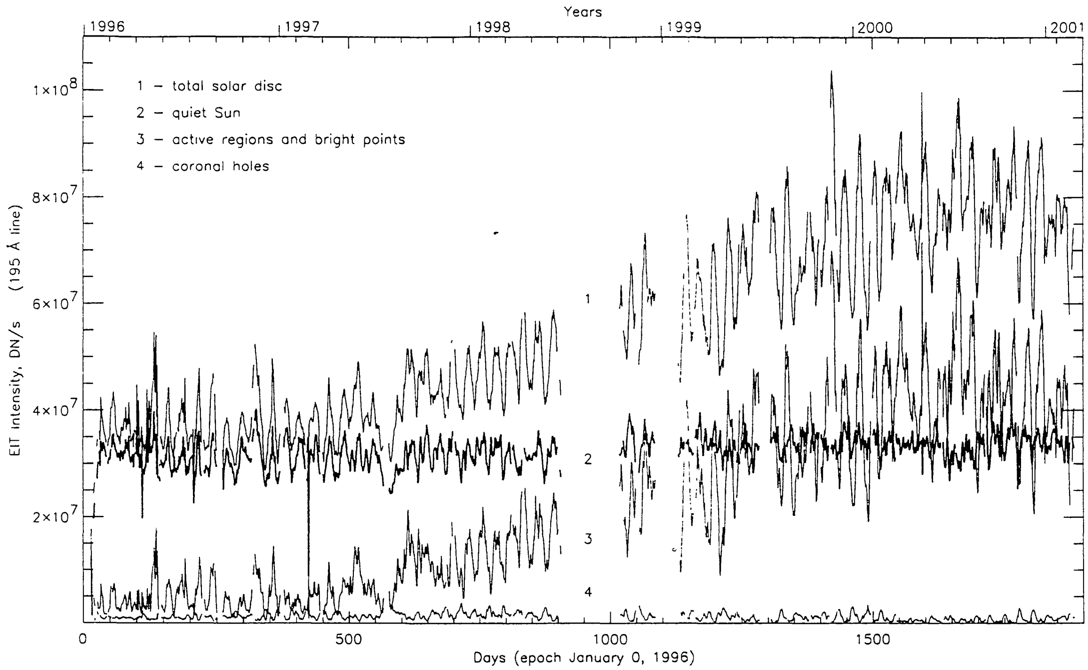

Figure 3. Variations of integral emission in the Fe XII line (195 Å) for: disc only (curve 1); disc "quiet Sun" (thick curve 2); disc active regions and bright points (curve 3); disc coronal holes (curve 4). The curves for the other three EIT bandpasses are similar.

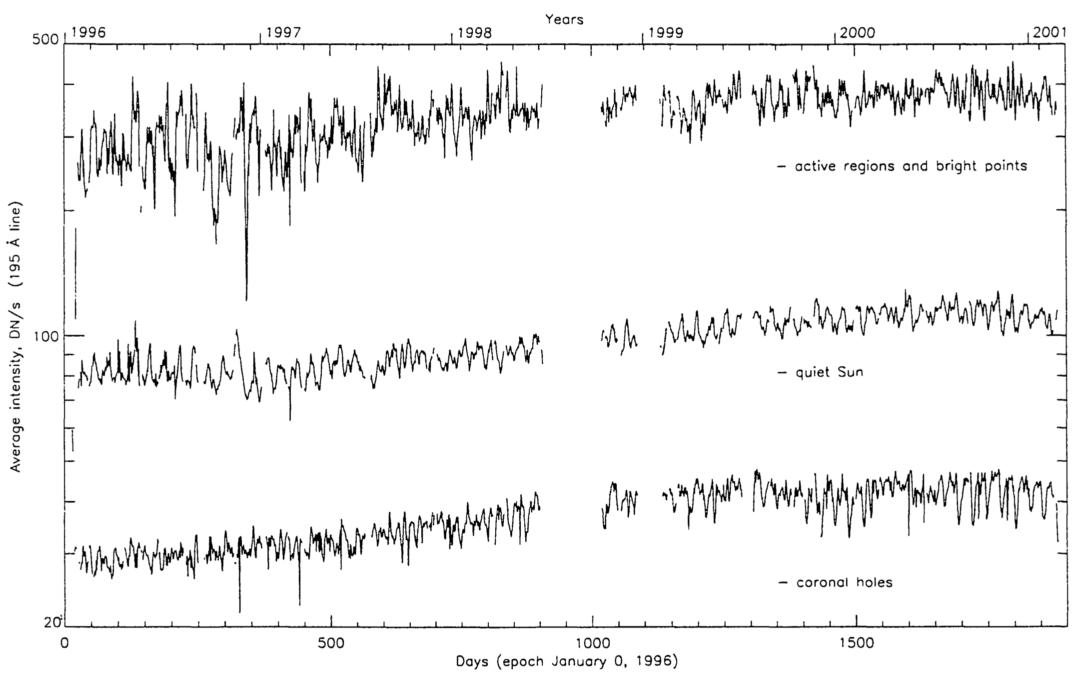

Figure 4. Variations of average intensity of different solar structures in the Fe XII line (195Å). The curves for the other three EIT bandpasses are similar.

We chose to consider only the solar disc region, inside the limb, because it provides the dominant part of the integrated intensity and the contributions of different solar structures are easy to distinguish there.

We report here only the results concerning Fe XII line (195 Å), but the analogous investigation of data obtained in other three EIT bandpasses leads to similar conclusions. We note, however, that the interpretation of our results for the He II line (304 Å) is not straightforward because the presence of the network disturbs simple representation of the Sun as consisting of coronal holes, "quiet Sun", active regions and bright points. Thus, the data obtained in this bandpass need additional investigations.

In order to determine the role of different structures in the longitudinal asymmetry, we have investigated the relative contribution of pixels with different intensities I to the disc EUV brightness variability. The corresponding statistical histograms are shown in Figure 2. For a typical minimum-activity brightest hemisphere (Figure 2, left panel, curve 1), we can clearly distinguish the following contributions to the total intensity: coronal holes ($I < 40$ DN/s), active regions and isolated bright points ($I > 200$ DN/s). The broad maximum around $I = 80$ DN/s – 100 DN/s and its shoulders are mainly produced by the most probable brightness elements. The largest fraction of the integrated intensity (77%) is contained in the intermediate brightness range 40 DN/s $< I <$ 200 DN/s; these elements are globally distributed over large areas (up to 2/3 of the whole surface of the Sun) and generally correspond to the "quiet Sun". Now, in the equivalent plot for the minimum-activity darkest hemisphere (Figure 2, left panel, curve 2), the only difference is the absence of any extended active regions; so, the upper tail of the distribution ($I > 200$ DN/s) is due exclusively to EUV bright points.

The same distributions were obtained for the rising phase and maximum of the activity cycle (Figure 2, middle and right panels correpondingly, curves 1 and 2). Now 40–60% of the total intensity is contained in the intermediate brightness pixels and the contribution of active regions is increased.

The difference between the brightest and darkest hemispheres during one solar rotation is statistically distributed as shown by curves 3 in Figure 2. During the minimum of activity (Figure 2 left panel), 60% of this difference is provided by the increase in the "quiet Sun" contribution, 48% – by the increase of the active regions and bright points contribution, and 8% should be subtracted as the decrease of the coronal holes contribution. In the rising phase these numbers are correspondingly 8%, 97% and −5%, in the maximum: −1%, 105% and −4%. Hence, during the minimum phase the contribution of the "quiet Sun" to the 27-day modulation of the total solar disc intensity is comparable to the contribution of active regions and bright points.

Variations of the integrated disc intensity as well as different contributions to the disc brightness are all shown in Figure 3. Here, one can see that during the activity minimum intermediate brightness pixels (curve 2) contribute the largest part of the integrated disc intensity (curve 1) and significant part of its variability. The integrated "quiet Sun" intensity remains variable during the activity maximum. Figure 4 shows that the average quiet Sun brightness exhibits the rotational modulation even during the maximum of the current solar cycle.

3. CONCLUSIONS

- Variations of the integral intensity of the EUV "quiet Sun" exhibit rotational modulation, i. e. global longitudinal asymmetry.
- During the epoch of low solar activity the contribution of the "quiet Sun" to the rotational modulation of the integral solar disc intensity is comparable to the contribution of active regions and bright points.
- The average intensity of the "quiet Sun" exhibits the rotational modulation at least throughout half of the solar cycle observed by SOHO.

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