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PROPERTIES OF BRIGHTENINGS SEEN IN CDS MOVIES

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ABSTRACT

We discuss movies obtained with the Coronal Diagnostic Spectrometer (CDS) onboard the Solar and Heliospheric Observatory (SOHO) and recorded at a cadence of 30 seconds during 4 hours in a quiet sun region. These movies are used to investigate brightness variations of solar features at different levels in the solar atmosphere.

We employ histograms and scatter-plot diagrams in order to gain a "statistical" view of these variations. Preliminary results are presented. We find significant variability at all time scales in all parts of the quiet Sun, from darkest intranetwork to brightest network. Such variations are observed in the chromospheric He I line, the transition region O V and coronal Mg IX lines. For the first 2 lines the relative variability is independent of brightness, while for the coronal line it increases somewhat with brightness. Finally, most of the variability appears to take place on time scales longer than 5 minutes for all 3 spectral lines.

Key words: chromosphere; transition region; corona; variability.

1. INTRODUCTION

The chromosphere, transition region and corona of the Sun are known to be highly dynamic on time scales of seconds to the solar cycle. Before the advent of SOHO, only a limited amount of data was available, often hampered by limited spatial and/or temporal resolution. For example, Porter et al. (1984) and Rabin & Dowdy (1992) reported on transition region brightenings (lasting typically less than 1 minute in the former case and longer than 5 minutes in the latter case). The latter found that most of the significant fluctuations last for $\leq$ 10 minutes, though a non-negligible amount of points show brightenings lasting over longer time scales.

Now huge amounts of new data from instruments onboard SOHO are available. Recently, some papers have reported first results on brightness changes obtained with such data. For example, Harrison (1997) reported on blinkers, i.e. strong brightenings that are located at network cell boundaries and last a few minutes. Walsh et al. (1997) observed similar events in an active region. Finally, Brekke et al. (1997b) also observed blinkers in the quiet Sun but additionally noted the presence of much longer-lived intensity variations.

2. OBSERVATIONS

The analyzed observations have been carried out using the Normal Incidence Spectrometer of CDS (Harrison et al. 1995) in its movie mode, i.e. with the $90'' \times 240''$ slit. In this mode a filtergram covering a part of the solar surface corresponding to the slit size is produced in selected spectral lines. Spectral information within each spectral line is lost. The target was a quiet region at Sun center (December 3, 1996). He I 584.33 Å ($2 \cdot 10^4$ K), O V 629.74 Å ($2.5 \cdot 10^5$ K) and Mg IX 368.06 Å (10^6 K) were recorded simultaneously at a cadence of 31 seconds during a total time of 4 hours. The actual exposure time was 25 seconds and the overhead amounted to 6 seconds. It should be noted that the Mg line is actually a blend of a Mg IX (10^6 K) and a Mg VII ($6 \cdot 10^5$ K) line (Brekke et al. 1997a). Figure 1 shows a sample frame in each spectral line. The pannels correspond from left to right to the He I 584 Å, O V 629 Å and Mg IX 368 Å lines. Note that the intensity is scaled individually for each of them.

In this paper we present preliminary results of a statistical analysis of the brightness variations observed in the quiet Sun using CDS movies lasting 4 hours. Beside the standard reduction procedure, we used cross-correlation techniques (in the Fourier domain), as well as pointing information provided by the instrument to compensate for solar rotation and changes in the telescope pointing. Therefore each pixel followed the same points on the solar surface during the whole extent of the observations. The size of the resulting field of view is $67'' \times 217''$, with the pixel size being $1.68'' \times 1.68''$. We also corrected, to first order, the data for slow evolution of the geo-

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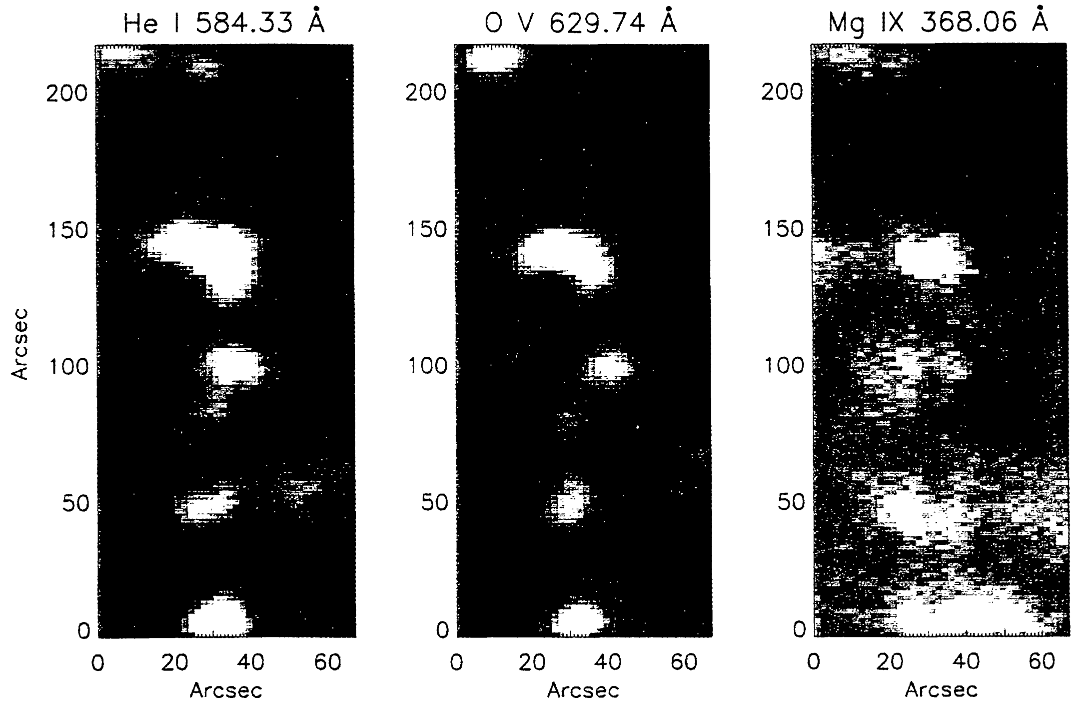

Figure 1. A sample of quiet-sun CDS movie frames. From left to right: He I 584 Å, O V 629 Å and Mg IX 368 Å. The field of view corresponds to $67 \times 217''$. Bright colors correspond to higher intensities.

metrical structure of solar features by removing the long-term linear trend for each pixel. This was done separately for each spectral line.

The typical S/N values amount to 28.8 for the He I, 25.4 for O V and 24.0 for Mg IX. In the following we analyze the rms of temporal intensity variations for each of the 5160 pixels (each corresponding to a different spatial location).

3. RESULTS

3.1. Reality of the Brightness Variations

Figure 2 shows a scatter plot of the ratio of the rms intensity fluctuations to the noise as a function of the intensity for the O V line. The rms was determined over the whole duration of the observations (4 hours). The noise and the intensity are averages over this period of time. The noise is defined here as photon noise, i.e. $\sqrt{\text{Intensity}}$.

We see that significant variations are observed at all intensities. All the fluctuations lie above an rms/noise ratio of 1.0 meaning that almost all are real intensity variations, and not due to the noise. We checked if a geometrical evolution of the brightness structures could lead to such variations by removing the long-term linear trend for each pixel. No significant changes in the shape of the plot was noticed before and after this correction (only results after the removal of such trends are plotted here).

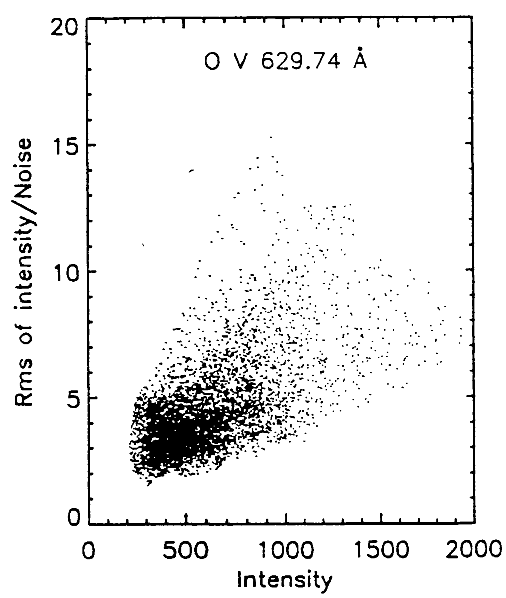

Figure 2. Scatter plot of the intensity-rms to noise ratio as a function of intensity for the O V line at 629 Å. The intensity is given in photons/cm^2/arcsec^2/sec.

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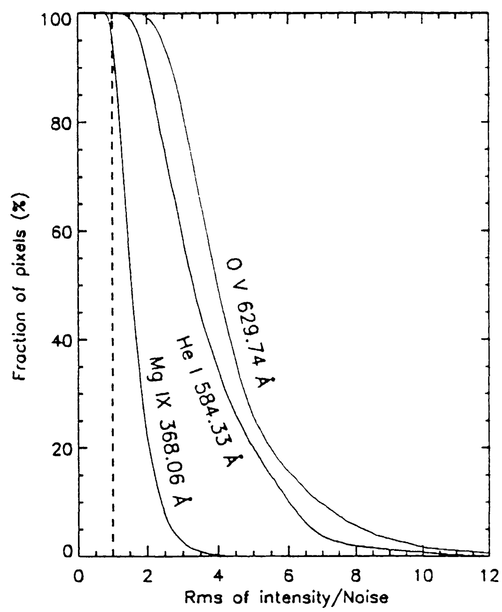

Figure 3. Fraction of significantly variable points. Each point on one of the curves represents the pecentage of pixels with an intensity-rms/noise ratio lying above the corresponding value on the abscissa. The different curves correspond to the different spectral lines. The vertical dashed line marks rms values corresponding to the 1σ noise level.

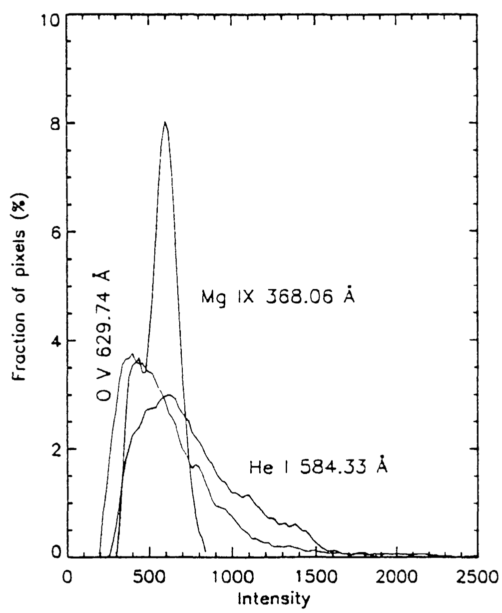

Figure 4. Histogram of the intensity values for the 3 spectral lines.

This suggests once again that most of these fluctuations are intrinsic variations of the upper atmosphere. The overall shape of the corresponding plots for the He I and Mg IX lines are similar to Fig. 2, although the S/N ratio is somewhat lower for He I and significantly lower for Mg IX. This is shown more clearly in Fig. 3, which exhibits the percentage of pixels with an rms/noise ratio lying above the corresponding value on the abscissa. The different curves represent the different spectral lines. The vertical dashed line marks rms values corresponding to the 1σ noise level. The most significant variations are observed in the O V line, while the Mg IX line shows the least significant variations. Figure 3 tells us that basically every point in the quiet sun is significantly variable at the 1σ level in the upper chromosphere, transition region and corona (in agreement with Rabin & Dowdy 1992). This does not imply that the strongest absolute temperature variations occur in the temperature range of formation of the O V line, since the amplitudes of these changes also depend on the sensitivity of the different lines to temperature and density.

3.2. Intensity Distribution

Histograms of the intensity at each pixel averaged over the 4 hours observing time is plotted in Fig. 4. The intensity distribution of the Mg IX line differs strongly from those of the two other lines. Firstly it doesn't have a high intensity tail and secondly it shows a double peak. Since this line is a blend of a Mg IX and a Mg VII transition, which are formed at different temperatures, it is unclear without modelling to what extent this blending causes the 2 peaks and to what extent the bimodal distribution is showing two coronal populations with different densities. The tail of high intensity points seen in He I and O V are due to the network (the bright features in the left and middle pannels of Fig. 1). In the image made in the Mg IX line the network is still recognizable, but at a much lower contrast, and covering a larger fraction of the solar surface, which leads to the absence of a high-intensity tail in the histogram of this line.

3.3. Relative Intensity Fluctuations

Figure 5 shows the relative intensity fluctuations for each line as a function of time-averaged intensity. The solid line depicts the rms/noise averaged over 172 points with neighbouring intensity values, as a function of intensity. The dashed lines indicate the 1σ level uncertainties. These curves are almost flat, at least for the He I and O V lines, implying that the relative intensity variations do not depend on the absolute intensity in a spectral feature and that the same behaviour applies for very different temperatures. Thus, the relative brightness fluctuations are equally strong in the network as in the intranetwork. For the Mg IX line a weak correlation between the relative intensity fluctuation and the absolute intensity exists. Remember that the fluctuations observed in this line are much less reliable than those observed in the two other lines (c.f. Fig. 3). The correlation coefficients obtained between the rms of intensity/intensity and the intensity amounts to -0.05 for He I, 0.08 for O V and 0.33 for Mg IX. For the determination of these coefficient all the points were used.

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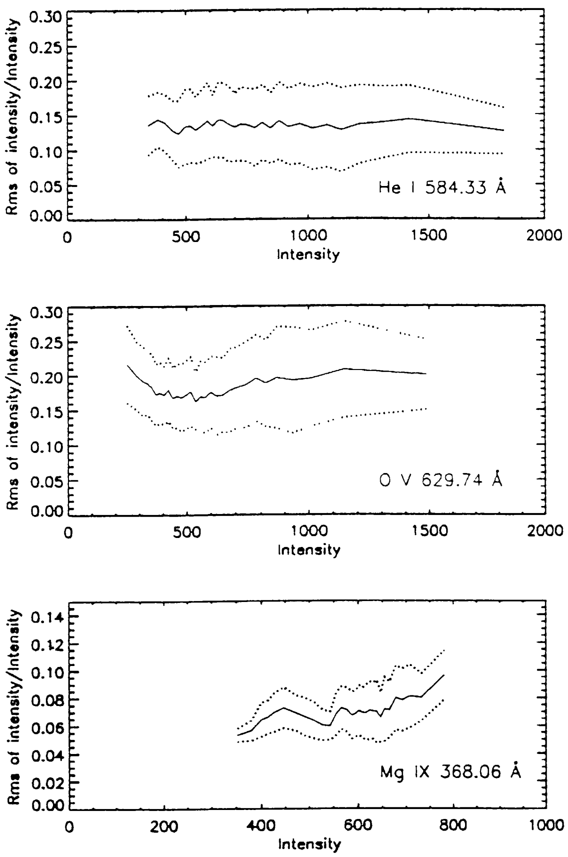

Figure 5. Plot of the rms/intensity ratio as a function of the intensity for each spectral line. Solid curves: values binned over 172 points with similar intensity. Dotted curves indicate the 1σ uncertainties.

Histograms of the relative intensity fluctuations on different time scales are plotted in Fig. 6 for the 3 spectral lines. The thin solid curves represent the distribution of brightness fluctuations occuring over time scales of 5 minutes or less, while the thick solid curves describe the distribution of the rms determined over the whole length of the observations. In order to determine the brightness fluctuations occuring over time scales of 5 minutes or less, we cut our 4 hour sequence into 5 minute pieces. For each of them we determined the rms of the intensity for each pixel separately. Finally we also looked at the relative brightness changes occuring on time scales larger than 5 minutes (and up to 4 hours). For that purpose, we determined the average intensity observed in each 5 minute interval and analysed the fluctuations of these intensities over the complete length of the observations.

The average fluctuations observed over short time scales (i.e. $\leq$ 5 min, thin solid curves) show much smaller amplitudes than those observed over long time scales (i.e. $\leq$ 4 hours, but $\geq$ 5 min., dashed curves). No significant difference is observed between the curve relating to fluctuations over time scales larger than 5 minutes (dashed curves) and those relating to the fluctuations taking place on all time

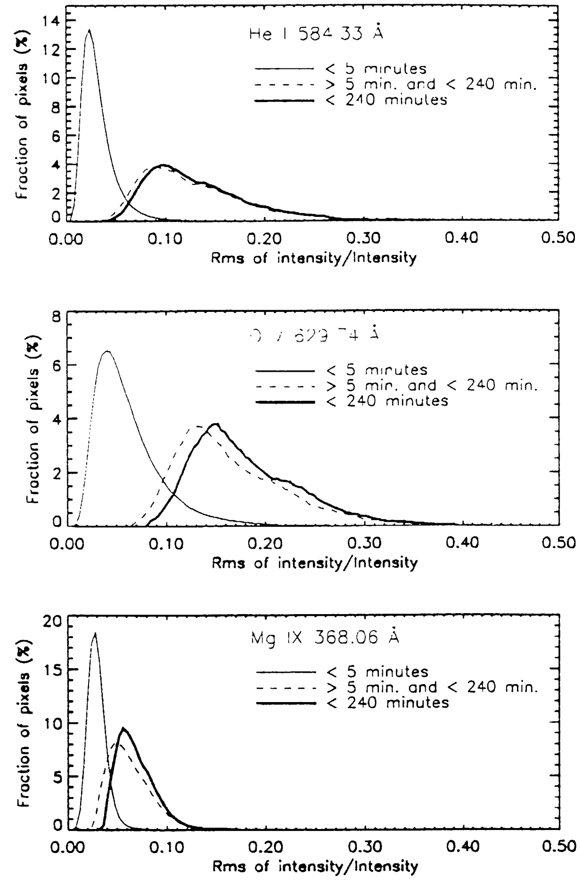

Figure 6. Histograms of intensity-rms/intensity. The thin solid lines correspond to variations with time scales shorter than 5 minutes, the dashed curves to variations with time scales larger than 5 minutes and the thick solid lines to all variations with time scales above 1 minute and below 240 minutes (i.e. the full period of 4 hours).

scales, between 1 minute (given by our sampling rate of once every 30 seconds) and the full observed time interval of 4 hours (thick solid curves). It therefore seems that the brightness fluctuations are dominantly due to slow brightness changes and not to sharp impulsive events.

4. CONCLUSIONS

We have investigated the brightness variations observed in quiet-sun CDS movies obtained simultaneously in He I 584.33 Å, O V 629.74 Å and Mg IX 368.06 Å. We find that all the points from the darkest intranetwork to the brightest network are significantly variable on all time scales. For the chromospheric (He I) and transition region (O V) lines the relative variability is independent of brightness, while for the coronal line (Mg IX) a weak increase in variability with brightness is detected. Most of the variability observed in all 3 lines seems to take place on time scales longer than 5 minutes.

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