VARIABILITY OF THE SOLAR He I 10830 Å TRIPLET

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Abstract. The He I 10830 Å triplet gives a unique view of the solar chromosphere. Digital spectroheliograms have been made regularly since early 1974 using this line and the NSO Vacuum Telescope on Kitt Peak. For many purposes (detection of coronal holes, giant two-ribbon flares, and dark point events) these images are sufficient. A Sun-as-a-star signal is also produced by averaging all the pixels in each daily image. To calibrate this 'irradiance' signal in terms of line equivalent width, a comparison is made with integrated sunlight spectrophotometric measurements obtained less frequently. After correction for the effects of water vapor blends, we find a linear relation between the two measurements. The daily averages have been assembled into a time series covering nearly two solar cycles. This time series shows cycle modulation of about ±30% and rotational modulation of about ±10%. The general variation is similar to that of other activity indices but with some interesting small differences. Since images are available, it has been possible to decompose the full disk index into components due to plages, filaments, coronal holes and background. At all times during the cycle, most of the signal comes from the background but most of the variability from plages.

Key words: He I 10830 Å – infrared: stars – Sun: activity – Sun: chromosphere

1. Introduction

Neutral helium lines are particularly interesting because they arise exclusively from chromospheric material while at the same time ultraviolet radiation from the overlying corona contributes significantly to their formation (*e.g.*, Avrett, these proceedings). Several papers at this symposium deal with the He I 10830 Å triplet and a recent review of observations was presented by Shcherbakov and Shcherbakova (1990). Uniquely among ground-accessible spectrum lines, observations of the Sun using helium lines show the signatures of coronal features such as holes, bright points (Harvey *et al.*, 1975) and the heated foot points of large magnetic structures associated with mass ejections (Harvey, Sheeley, and Harvey, 1986; Harvey, these proceedings). However, these coronal signatures are rather subtle; helium images are primarily excellent pictures of the chromosphere. The strongest helium line observable from the ground is the 10830 Å line (actually a triplet). A potentially interesting line at 2.058 μm is blocked by strong telluric absorption. A program of daily, digital 10830 Å spectroheliograms was started in 1974 using a 512-channel magnetograph (Livingston *et al.*, 1975a) and a 70-cm vacuum telescope on Kitt Peak (Livingston *et al.*, 1975b). This paper is an overview of some of the results and a preliminary attempt to decompose a full-disk averaged signal into its various sources.

2. Observations

A full-disk observation consists of four 512-arcsec-wide scans of a solar image across the entrance slit of a 10.4-m spectrograph. It takes approximately 40 minutes to

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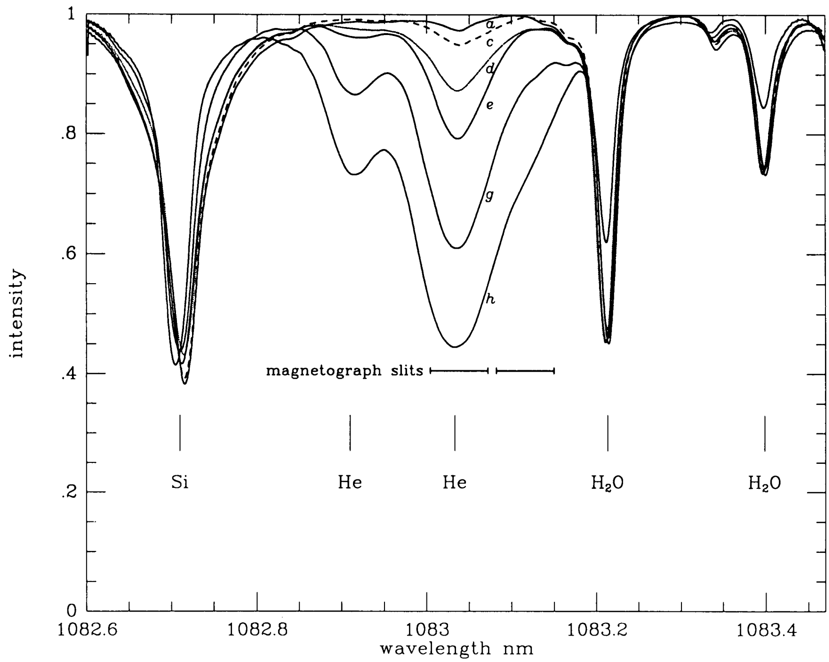

Fig. 1. Disk spectra of various solar features. The spectral windows used for the daily observations are indicated. Features *a* and *c* are light parts of the background, *d* is a typical network element, and *e* – *h* are filaments and plages.

make these scans. During the scans, at each arcsec on the disk, two spectral windows are sampled. A signal is calculated that is the ratio of the difference to the sum of these samples. Figure 1 shows these windows along with the spectra of various solar features. Each window has a width of 0.68Å and there is a 0.16Å gap between them. The (non-ideal) choices of windows and processing algorithm were fixed in 1974 by mechanical, optical and computer constraints associated with the magnetograph observations.

By a fortunate accident, both spectral windows include water vapor contributions that change nearly identically, and the calculated signal is almost free of water vapor contamination (*cf.* Breckinridge and Hall, 1973). Because the helium line is usually weak, the calculated signal is also largely free of photospheric contributions. In particular, sunspots and granulation do not appear in the images.

The calculated signals are recorded on magnetic tape and processed later in various ways. The first step is to remove streaks and limb darkening from each scan line by subtracting a model with parameters determined by weighted least-squares fitting. Next, the images are filtered by a spatial frequency notch filter. At this point, the original data are discarded and the processed images are useful by themselves for many purposes. Further processing includes remapping each image to a latitude-longitude format at reduced resolution and producing a Sun-as-star

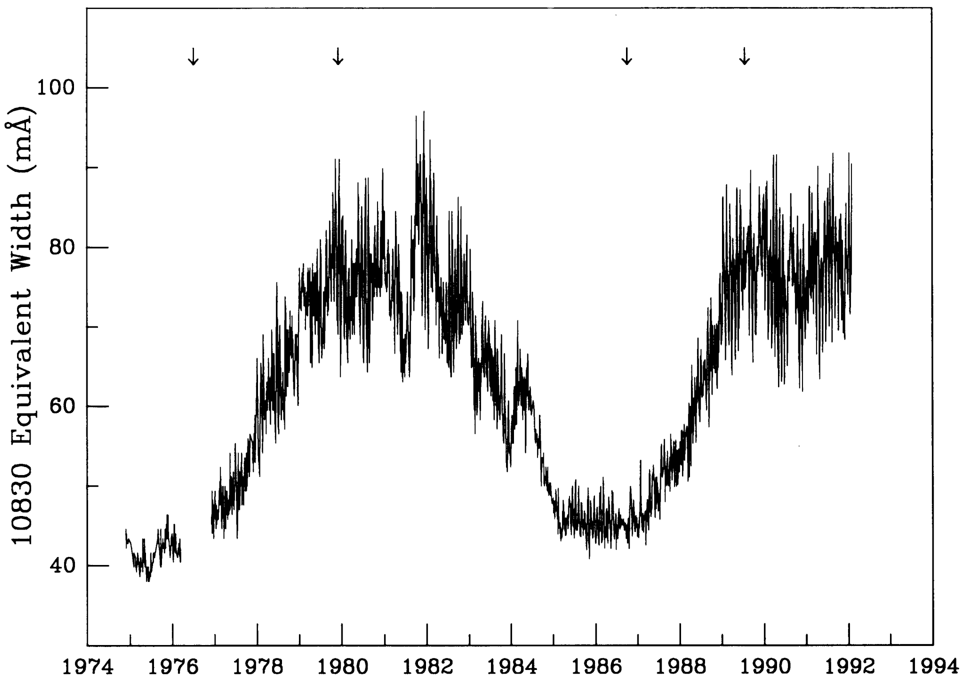

Fig. 2. Daily measurements of the disk-averaged strength of the 10830Å line 1974-1992. Arrows indicate the times of sunspot number maxima and minima.

signal by averaging all the disk measurements. These two reductions are the basis of the rest of this paper. All of the helium data are archived and available to the research community.

The disk-averaged signal (except for minor effects of the destreaking) indicates the strength of the helium line if the Sun were observed as a star, without any spatial resolution. This signal is instrumentally stable in time but is uncalibrated. We transform the instrumental scale to equivalent width by comparing it with high accuracy, monthly measurements of the integrated Sun equivalent width corrected for blends of water vapor lines (Livingston, Wallace, and White, 1988; Livingston *et al.*, 1991). Comparison of the two sets of measurements shows a linear relation between them. The best-fit linear relation is used to calibrate the daily measurements with a formal systematic uncertainty of a few mÅ. The same calibration can be applied to the resolved maps but this requires a rather large extrapolation for strong 10830 features. This calibration assumes that the line equivalent width is proportional to line strength and that line shape changes are not important. This is unlikely to be true in detail and is probably the main source of scatter between the two sets of measurements.

Figure 2 shows the daily, disk-averaged measurements reduced to equivalent width units. Studies of earlier portions of these data have been published (Harvey, 1981, 1984). The main results of Figure 2 are that the helium signal averages 60 mÅ over the solar cycle with a $\pm 30\%$ cycle modulation and a roughly $\pm 10\%$ rotational modulation. To first order, the signal can be represented rather well by a single, biased sine wave. Curiously, although helium images are unlike solar images in any other spectral region of which we are aware, the disk-averaged helium signal is better correlated with variability in Lyα, 208 nm and total solar irradiance corrected for sunspots than other available solar activity indices (Lean, 1990; Donnelly *et al.*, 1985; Foukal and Lean, 1988; Willson and Hudson, 1991). This probably indicates observational defects in other chromospheric indices rather than a superiority of the helium indicator. Nevertheless, the result prompted us to investigate what solar features produce the helium full-disk signal. We are able to do this because resolved images are used to construct the signal.

3. Decomposition of the 10830Å Disk-averaged Signal

For this first attempt to decompose the 10830 full-disk signal we used the daily images mapped into latitude-longitude format. These maps are routinely averaged with weights into single maps of each Carrington rotation. In digital form, a 7-year time series of helium line strengths vs. latitude along the central longitude meridian (6×10^6 values) was convolved with a weighting function that synthesized a daily full-disk average. This synthesis is plotted in the upper panel of Figure 3. It agrees well with the actual daily measurements included in Figure 2. Small differences can be attributed to low-pass temporal filtering that is part of the construction of the synthetic signal.

We decomposed the signal by assigning various ranges of the helium signal in spatially resolved maps (and also in corresponding maps of magnetic field strength) to various features and then synthesizing the daily signal from these various ranges. There is an unsatisfactory subjectivity and uncertainty about this procedure that we plan to reduce in future work. With that caveat, we first note that the variations of the individual components are principally due to changes in the fractional areas rather than strength variations. A notable exception is the background component which rises during high activity despite a decrease of the area of the disk classified as background. On a time scale of years, all the components except coronal holes follow the general rise of solar activity. It is clear that the background component always produces most of the 10830 disk-averaged signal. Its 20% increase from minimum (1986) to maximum (1989) may simply be due to a poor job of eliminating faint plage remnants, or the rise may be due to general enhancement of the background. The 27-day periodicity present during high activity suggests that the first explanation is part of the story but more detailed work is needed to determine how much. Notice that most of the variability on scales of years and 27 days comes from plages. Filaments contribute a surprisingly large fraction of the variability, presumably because they are the most intense features seen in neutral helium lines.

Following Foukal and Lean (1988), it is interesting to speculate about the level of solar irradiance that would be reached under prolonged conditions of no activity.

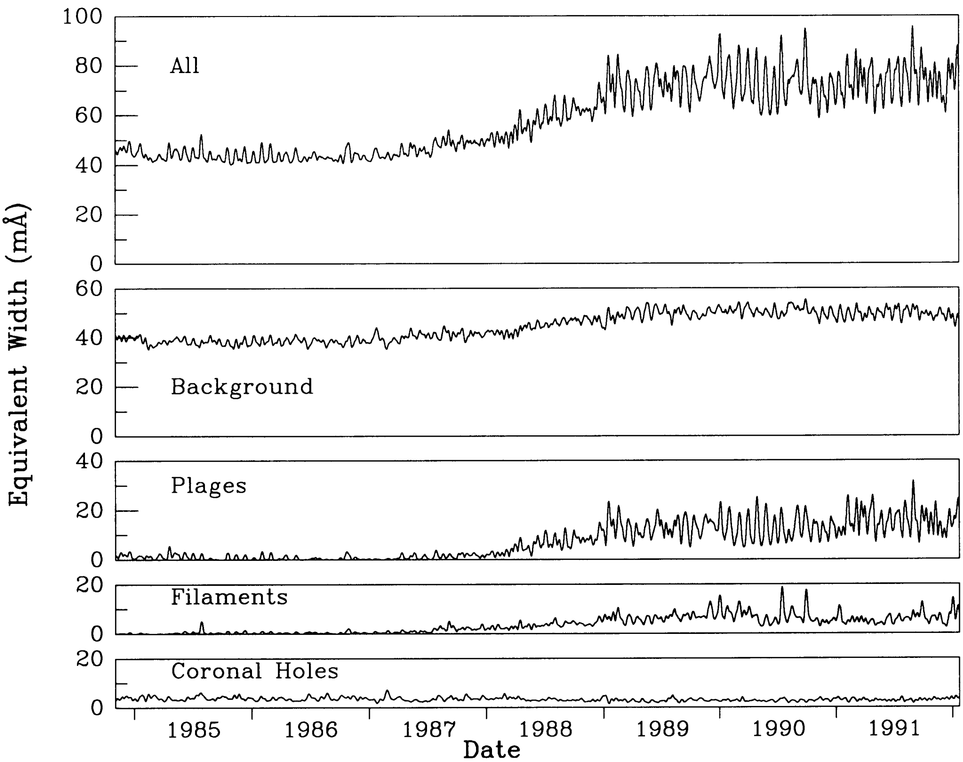

Fig. 3. Full disk signal synthesized from synoptic maps and decomposed into 4 sources.

Since the 10830 disk-averaged signal follows measurements of solar irradiance (corrected for sunspots) very well, and a decrease of 40 mÅ between 1982 and 1986 was associated with a decrease of sunspot-corrected solar irradiance of about 0.17%, we estimate that another 0.2% drop of irradiance might be possible if the activity that produces the 10830 line vanished entirely. In other words, the level of solar irradiance during the activity minimum of 1986 might be 0.2% higher than the level accompanying a prolonged cessation of activity. The spatial decomposition of the helium signal indicates that the background is the only possible source of such a drastic change. It is not at all clear that the relation between helium line strength and solar irradiance established for plages also holds for the small network elements in the background. Thus our irradiance change estimate should be considered as purely speculative.

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