Sun-as-a-star: Its Convective Signature and the Activity Cycle

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Abstract: From May 1980 to April 1990 we have observed several times a year the solar irradiance spectrum from 5000Å to 6300Å using the 1-m Fourier Transform Spectrometer. During the ascending phase of the solar cycle, spectrum line asymmetry diminishes about 15% as the total magnetic field encreases. At some epoch near the time of total magnetic field maximum, line asymmetry ceases to track surface magnetism and abruptly assumes a value appropriate to solar minimum.

1. Introduction

At the photospheric level the Sun's surface is covered by the pattern of granulation. High resolution spectra (e.g. Kirk and Livingston, 1968) show that the bright components of granulation are Doppler shifted to the blue while the dark are shifted to the red. These granular motions are attributed to convection driven by the outward transport of heat (Bray *et al.*, 1984). Spatially averaged this brightness-velocity correlation imparts an asymmetry to Fraunhofer lines formed in the high photosphere (e.g. Dravins *et al.*, 1981).

Apparently granular convection is slightly inhibited in the presence of surface magnetic fields so that the resulting line asymmetry is reduced (Livingston, 1982; Cavallini*et al.*, 1985; Immerschitt and Schröter, 1989; Brandt and Solanki, 1990). One explanation for this inhibition is that the presence of magnetic flux tubes, which have an observed preference for inter-granule lanes (Muller, 1989), crowds or confines the convective cells, forcing them to be smaller and convectively less vigorous.

Magnetograph observations indicate that the total amount of magnetic flux, i.e. $|F_+|+|F_-|$, crossing the solar surface varies through the activity cycle (Bruning and LaBonte, 1985). The measured magnitude of the change is sensitive to spatial resolution and the magnetograph zero level. Recently K. Harvey (1990) has derived a time history of the total field variation from Kitt Peak full disk magnetograms.

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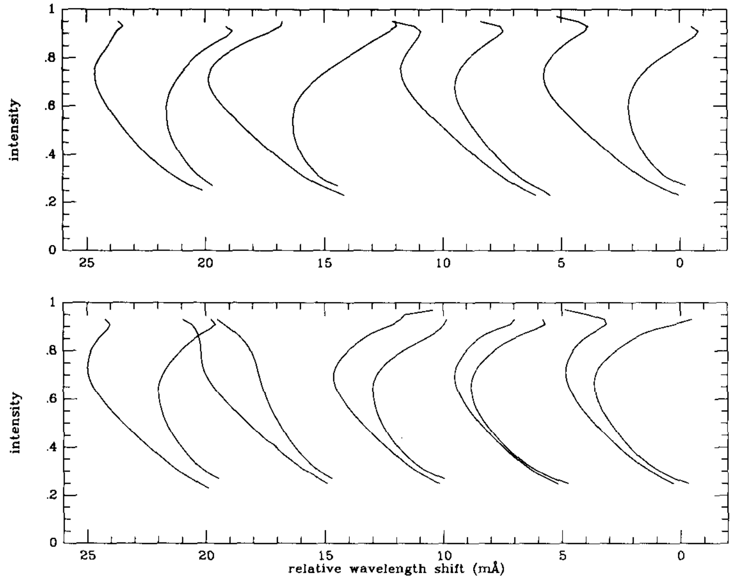

Fig. 1. Samples from the resolved disk with a resolution of about 2 arc-min comparing line bisectors for Fe 5217.4 Å in quiet Sun (left side of each pair) with plage. Although there is considerable variation, in part due to filling factor, in all cases the plage is relatively red shifted and displays less curvature.

She finds that the total field crossing the surface encreased by a factor of about 5 from minimum to maximum in cycle 21 (1976–1986).

The question we pose is this: Given the empirical evidence from the resolved disk that surface magnetism locally reduces line asymmetry, does the activity cycle variation in total field modulate full disk line asymmetry? If the answer is yes, then by observing changes in line asymmetry for other solar-type stars their state of magnetism might be deduced independent of the hard to measure Zeeman effect.

Observations aimed at the above question began in May 1980. Preliminary findings were presented in 1987 (Livingston, 1987), but at that time the temporal record was puzzling to interpret. The main feature was a dip in line asymmetry mid-cycle. Now we have an additional 3 years of data and the situation is clarified. The previous dip remains, of course, but now a new one has developed presumably at about the same phase as in the last cycle. Additionally a sensible relation is also found at the beginning of the cycle: At that initial phase, the magnitude of line asymmetry appears to depend on the total magnetic field.

2. Observations

Spectra in the wavelength interval 5000Å to 6300Å have been obtained with the 1-m FTS in integrated sunlight an average of 3.6 times a year from May 1980 to April 1990. This cadence is set by the availability of the 'visible light beam splitter' (most of the time the FTS is configured for the infrared) together with the vagaries of weather and telescope scheduling. Spectral resolution is about 1,000,000; see Deming (1987) for instrument details.

You-Ran Huang has prepared a list of 18 medium strength iron lines at these wavelengths (average excitation potential = 3.56 eV, average equivalent width = 73 mÅ). Her lines all have comparable bisector curvature and are unaffected by telluric blends. We parameterize bisector curvature as the displacement in mÅ between line core and a tangent to the blue shifted maximum of the line bisector. By averaging all FTS observations for a given day (typically 6 to 8) and then averaging the bisector curvatures for the 18 select lines we obtain a *mean curvature* for that date.

3. Results

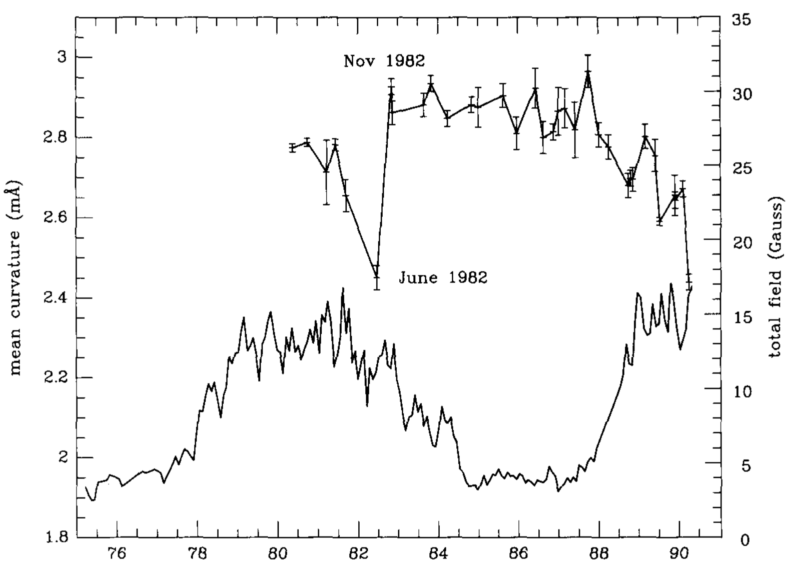

Fig. 2. Mean line asymmetry curvature as a function of date. The error bars reflect the number of FTS scans going into a single day's observation. Also plotted is the total magnetic field averaged over a Carrington rotation.

Figure 2 summarizes the archives up to the present. Of special interest is the abrupt change from June 1982 to November 1982. To demonstrate that the June 1982 bisectors were not anomalous we compare in Fig. 3 bisectors for a few specific lines between June 1982 and April 1990, epochs in which the value of the mean curvature was about the same. We see that these bisectors indeed are similar. On the other hand, if we try to match bisectors between June 1982 and November 1982 the interval of greatest change, we see that the bisectors are noticeably different, Fig. 4. This exercise lends credence to our assertion that the changes we observe are real and significant.

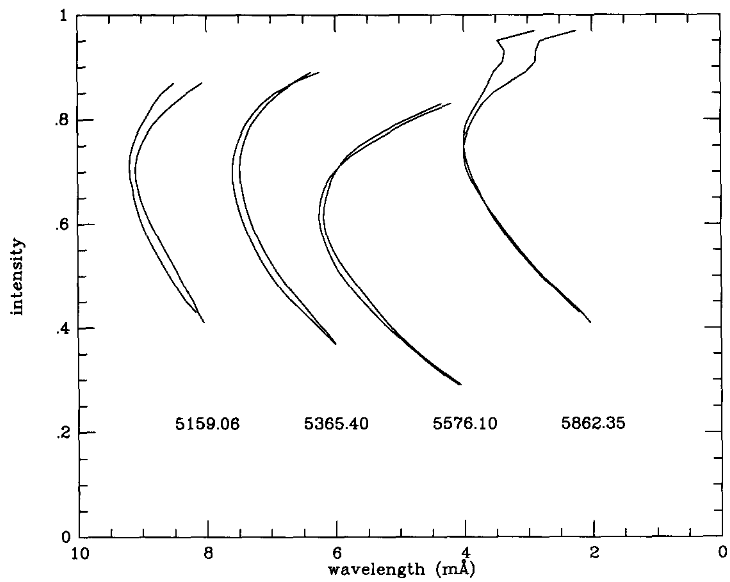

Fig. 3. Bisectors for typical iron lines June 1982 compared with April 1990, showing similarity and the high signal/noise of the observations.

4. Discussion

Included in Fig. 2 is a plot of the total magnetic field as provided by Karen Harvey. Notice that the sampling times for the two plots is disparate. Our mean curvature entries are for single days; the total field values represent averages over an entire Carrington rotation period (about 27 days synodic). Nevertheless, there is a trend toward an anti-correlation between mean curvature and total field from the time of solar minimum in 1986 through the onset of cycle 22. Our early data is also consistent with a congruent behavior during cycle 21, although our archives extend back only to 1980 and not to 1976 which was the previous minimum.

What is strange is the Jun 82 to Nov 82 discontinuity. Obviously we need to see the same process repeat following April 1990. Those observations have not yet been made. Lacking this future material we can only surmise that the process will repeat. Assuming it does, we conjecture that the cyclic process will continue as represented in Fig. 5.

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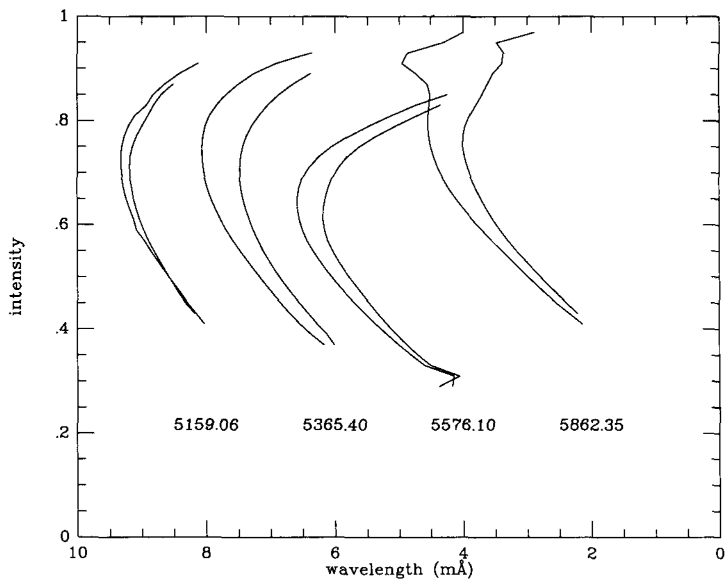

Fig. 4. How bisectors changed between June and November 1982.

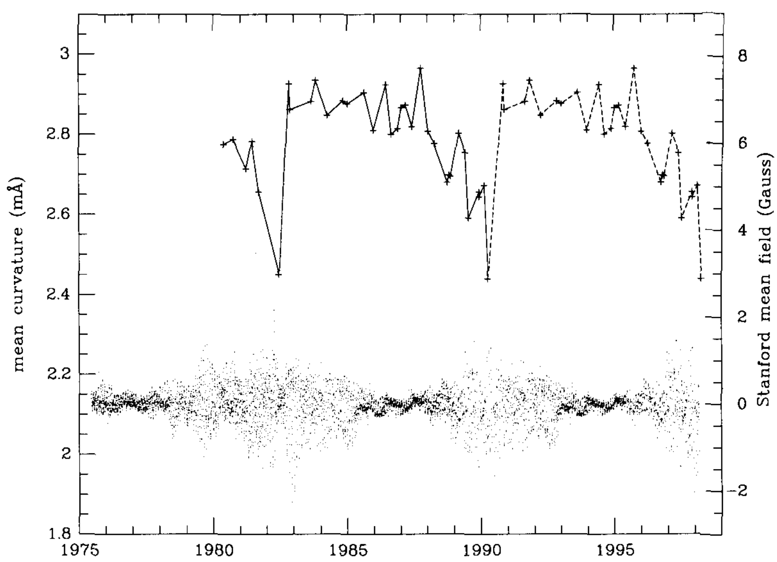

Fig. 5. Hypothetical extension of our observed line asymmetry temporal character assuming it is cyclic. Shown is the mean magnetic field as observed by the Wilcox Solar Observatory, Stanford.

We have no explanation for the Jun–Nov 82 discontinuity. Richard Muller has suggested that we may be sensing a result of the 'switching off' of *abnormal granulation* (Muller, 1988). Abnormal granulation is the visible fragmentation of granular structure found in magnetic regions when observed in sub-arc-sec seeing. Perhaps the creation of abnormal granulation depends in a non-linear way on total magnetic field. No doubt if our temporal sampling was more complete we would find this discontinuity replaced by a gradual transition.

In summary it appears that over the initial phase of the activity cycle line asymmetry diminishes by about 15%, and this reduction is anti-correlated with the Sun's total magnetic field. Abruptly mid cycle line asymmetry returns to near its solar minimum value. Why the relation between line asymmetry and the total field does not extend over the entire cycle is unknown. Only further observations can clarify this relationship.

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