MAGNETIC FIELDS AND CONVECTION: NEW OBSERVATIONS

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ABSTRACT

Fourier Transform Spectrometer observations of Fraunhofer line displacement and asymmetry suggest that granular convection is inhibited in regions of magnetic activity. We discuss the observations and a method for removing the effects of solar rotation. In integrated sunlight ("the sun-as-a-star") records of line asymmetries indicate that a significant reduction in the amplitude of the sun's convective signature took place between 1980 and 1982. To the extent that full disk line asymmetry arises strictly from convective motions, the results constitute strong evidence that magnetic activity influences (inhibits) convective motion on a global scale.

1. INTRODUCTION

A number of theoretical papers have considered the possibility that changes in surface, or immediately subsurface, magnetic fields can affect the efficiency of convection in the granulation layer and thus modulate the sun's luminosity (Thomas, 1979; Spiegel and Weiss, 1980; Dearborn and Blake, 1982). The analytic tools for diagnosing photospheric convective motion, viz. by Fraunhofer line asymmetry, has recently advanced (Dravins, et al., 1981; Dravins, 1982). The brightness-velocity correlation arising, from granular motions, causes line bisectors to have a 'C' shape; the middle of the C being blue-shifted relative to the laboratory value. For strong lines, such as Fe 5302, the core of the line is formed sufficiently high to be largely above the influence of granules and so is less displaced. In the far wings of the line, increased density in the line formation region coupled with the condition of flow continuity also results in reduced displacement. Realistic modeling by Nordlund (1982) provides a quantitative basis for the interpretation of the 'C' shape.

Although line bisectors can be obtained from conventional spectrograph data, the Fourier Transform Spectrometer (FTS) offers several advantages. First the FTS instrument profile is inherently symmetric so that no corrections are necessary. Second, many lines are obtained

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simultaneously. Third, the wavelengths are absolute after a zero point correction.

Inspired then by the predictions of theory, armed with the diagnostic tools of the line bisector, and taking advantage of the Brault 1-m FTS, we have made observations of line asymmetry in and out of magnetic regions. We have also examined the convection signature of the sun as a star. Details on methology and results are now presented.

2. OBSERVATIONS AND REDUCTIONS

While high spatial resolution information on granule dynamics could be valuable (see e.g., Muller, 1977), the slow scanning speed of the FTS eliminates that possibility. Rather than work at intermediate resolution we have chosen to observe at the very low resolution of 1 arc-min to better average over a large number of granules. Our observing procedure is as follows.

Referring to the day's full disk magnetogram as a guide, we center the FTS entrance aperture on a magnetic region, avoiding sunspots and pores. A scan is then made which takes about 90^s, covers $\lambda 0.500$ to $\lambda 0.600$ μm. This scan is designated "Plage 1". Next we move to a nearby position that is relatively clear of fields and at about the same limb distance. Another scan is made and this becomes "Quiet 1". We continue taking such pairs of active-quiet scans until the magnetic concentrations on the solar disk have been fairly sampled. Typically a dozen regions are observed on a given day and to date about 50 pairs of scans in all have been acquired.

After transforming the data, for each line on the Dravins, et al. (1981) list, we insert the laboratory wavelength of Crosswhite (1958). We then compute the profile bisector on an absolute scale taking account of the gravitational redshift and the usual Earth-Sun Ephemeris corrections.

There remains a component of velocity between Plage 1 and Quiet 1 due to solar rotation. To remove this rotation part we note the difference in wavelength between the cores of Mg 5172 in Plage 1 and Quiet 1, and apply this difference as a correction to the other pairs of Fe line data sets. The assumption here is that the granulation signal is practically absent in the core of Mg 5172 and that the only other velocity difference is due to rotation. No doubt the 5-minute oscillation introduces some disturbing error, but the effect is reduced by the large sample population.

3. RESULTS

Figure 1 illustrates the behavior of 95% of the 50 regions sampled. The non-magnetic (or quiet) bisector almost always has greater displacement to the blue and a greater amplitude of curvature than the magnetic region (or plage). Only for regions very near the limb does this rule fail. We may mention that g = 0 lines are indistinguishable from Zeeman

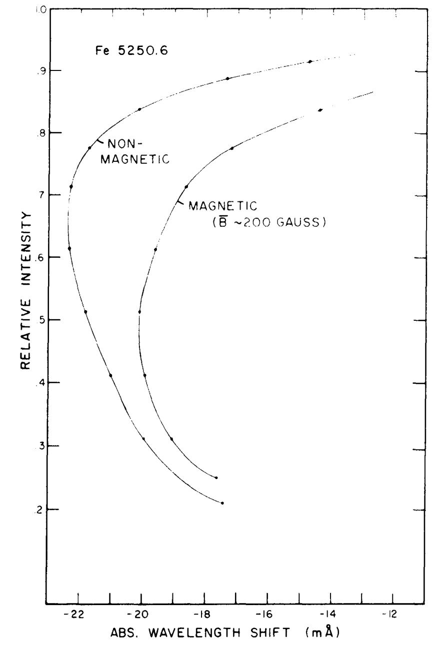

Figure 1. Line bisectors of Fe 5250.6 in and out of magnetic regions. In this example solar rotation has not been removed.

sensitive lines; from which we conclude that polarization effects play little or no role.

We have not yet been successful in determining the FTS zero point correction and thus placing the bisectors properly on an absolute velocity frame. The problem has been the wavelengths of the A-band of atmospheric oxygen which were observed for this purpose. The Babcock and Herzberg (1948) values show an internal dispersion of more than 1 mÅ which is totally inadequate. Brault and Lerner (1982) are preparing a set of revised O_2 wavelengths.

In addition to observing disk features it is easy to feed unfocused sunlight to the FTS and thus observe the "sun as a star". The resulting bisectors are remarkably stable. If we assign a velocity of zero to the core of a strong line such as Fe 5302.3 then the standard deviation of the blue shifted component is less than 0.1 mÅ for 6 observations on a given day. We have obtained a number of full disk observations since May 1980. Within the λ0.500 -λ0.600 μm window there are several relatively unblended lines similar in strength to Fe 5302.3. The bisectors of these lines have been averaged to yield Figure 2.

4. CONCLUSIONS

In agreement with the theoretical predictions it appears that granular convection is inhibited in regions of high magnetic flux. As this

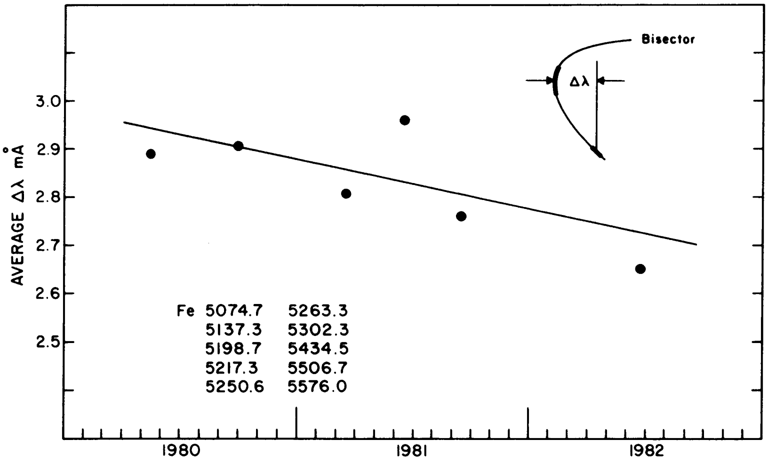

Figure 2. Full disk line bisector curvature, Δλ, showing decrease with time for the average of 10 similar Fe lines.

inference is based on low spatial resolution data, we still need high resolution observations to determine the role of facular points and decide whether or not the inhibition is global or localized.

The fact that full disk bisectors have diminished ~10% over the past two years suggests to us that there has been a global reduction in the vigor of granular convection (see also Livingston, 1982). Although the total surface magnetic flux has not increased lately, it has been redistributed. Initially confined to newly born sunspot umbrae, flux is now being distributed over the entire globe, presumably by the random walk process. Without additional new flux, a growing fraction of the sun's surface is threaded by magnetic fields with a consequent reduction in granular convection.

REFERENCES

Babcock, H. D. and Herzberg, L.: 1948, Astrophys. J. 108, pp. 167-190.
Brault, J. and Lerner, R.: 1982, private communication.
Crosswhite, H. M.: 1958, Johns Hopkins Spectroscopic Report No. 13.
Dearborn, D. S. P. and Blake, J. B.: 1982, Astrophys. J. 257, pp. 896-900.
Dravins, D., Lindegren, L. and Nordlund, Å.: 1981, Astron. Astrophys. 96, pp. 345-364.
Dravins, D.: 1982, Ann. Rev. Astron. Astrophys. 20 (in press).
Livingston, W. C.: 1982, Nature 297, pp. 208-209.
Muller, R.: 1977, Solar Phys. 52, pp. 249-262.
Nordlund, Å.: 1982, Astron. Astrophys. 107, pp. 1-10.
Nordlund, Å.: 1982, Astron. Astrophys., (in press).
Spiegel, E. A. and Weiss, N. O.: 1980, Nature 287, pp. 616-617.
Thomas, J. H.: 1977, Nature 280, pp. 662-663.

DISCUSSION

ZWAAN: Since you have measures of line asymmetries in plages, and you may estimate filling factors for plages, you may estimate the full-disk effect, and compare with your full-disk measurements — did you try?

LIVINGSTON: Yes, but our resulting plage filling factors were too large — about 20% . We plan more work on this.

SCHÜSSLER: I have a comment and a question. Comment: Macris has observed that granules are smaller than average in the vicinity of sunspots. This may have something to do with your work. Question: Would you not expect strong variations in emergent intensity for a strong magnetic influence on convection?

LIVINGSTON: Yes, and it was this expectation (with H. Holweger), looking for solar luminosity variations, that led us to this work in the first place.

SHEELEY: What have your integrated K-emission measurements done during this same 2–3 year interval? If the K-line flux were related to magnetic flux, then it should have gone up (according to Bob Howard's magnetic-flux measurements) rather than down as the sunspot number fell during 1980 and 1981.

LIVINGSTON: The K index has simply been fluctuating since 1979. We see no systematic trend up or down yet. As a matter of fact, in my opinion we are now at a new phase of the solar cycle with respect to the correlation between plage and the K intensity. We are at a phase when I think the sun is covered with so much network that the individual plages are beginning to affect the integrated signal from the sun less and less. This phase starts at sunspot maximum and continues on for some time, and it is a little different from the first leg of the cycle, when there was such a good correlation.

KEIL: I have two comments. (1) Pete Worden and I have noted that the K index and K intensity have not yet started to decrease with the declining phase of this solar cycle although the amount of plages has decreased considerably. There appears to exist a lag between the disappearance of plages and a decrease in chromospheric emission. (2) Peter Foukal and I have observed the difference between bisectors of quiet sun line profiles and profiles formed in the solar network. I have computed how much convection would have to be supressed to give the observed bisector shift between the quiet sun and the solar network. The shift can be modelled by either decreasing the amplitude of the convection by about 10% throughout the network, or by assuming that about 10% of the area in the network exhibits no convection, while the rest of the area has normal convection.

GRAY: When I received a preprint fom Bill Livingston showing the remarkable relation in his second figure, I did not chew on it the way the slide projector did, but I immediately went to my stellar bisector data to see if such an effect existed there. I first looked at several exposures of Arcturus and found no changes there. The errors, however, were found to be $\sim \pm 25$ m s^{-1}. Then I selected several pairs of stars by spectral type. In most of the pairs, there are no significant bisector differences at this error level, but in one K0 V set (70 Oph A vs. σ Dra) there is a distinct systematic difference shown by all lines. I do not know if there is any connection here with the solar results of Livingston, but at least we are able to see bisector differences, and are potentially in a position to find in stars what he has seen in the sun.