GRANULATION LINE ASYMMETRIES

1. INTRODUCTION

More than 30 years ago Voigt (1956) and Schröter (1957) proposed inhomogeneous solar models in order to explain the center to limb variation of the asymmetries in the infrared Oxygen triple resp. the limb-effect of middle strong Fraunhofer lines.

In these models the rising and sinking elements have a strong velocity gradient leading to intense line-asymmetries. The line-asymmetry of the individual components can amount to 20 mÅ as well as blue and red shifted. Asymmetries of this magnitude have not yet been observed though Kavetsky and O'Hara (1984) find stronger asymmetries in the individual components as had been known from spatially unresolved spectra. The line asymmetries of spatially unresolved spectra (C-shape) are about 5 mÅ as for example Brandt, Schröter (1982) or Cavallini et al. (1982) showed.

Voigt (1956) and Schröter (1957) compose the measured line-asymmetries of components with a higher line-asymmetry. Dravins (1975) explains the observed asymmetry as a superposition of two symmetric line profiles thus the individual components having no velocity gradient.

Recently performed granulation model calculations by Steffen (1987) show that for spectra with high spatial resolution one would expect line-asymmetries up to 0.7 km s⁻¹ (13 mÅ) blue-asymmetric and up to 2 km s⁻¹ (36 mÅ) red-asymmetric. The asymmetry in the spatial unresolved spectrum is 0.2 km s⁻¹ (3.6 mÅ); this was calculated for the Ti I₁-line (λ 5335.7 Å).
New observations with enhanced spatial resolution should verify if the line-asymmetries increase (Steffen) or decrease (Dravins).

2. OBSERVATIONS AND REDUCTIONS

The observations were done on July 20, 1987, with the 45 cm Gregory-Coudé Telescope at Izaña (Tenerife). We observed four different Fe-I lines near the disc center. There was no CaII-activity seen on the slit jaws. The wavelengths of the lines are given in Table 1 with their corresponding equivalent widths.

<table>
<thead>
<tr>
<th>Line Nr.</th>
<th>Wavelength</th>
<th>Equivalent width</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>6494.499 Å</td>
<td>34 mÅ</td>
</tr>
<tr>
<td>II</td>
<td>6494.994</td>
<td>165</td>
</tr>
<tr>
<td>III</td>
<td>6495.740</td>
<td>42</td>
</tr>
<tr>
<td>IV</td>
<td>6496.472</td>
<td>69</td>
</tr>
</tbody>
</table>

The dispersion of the used spectrograph was 5.1 mm/Å. The spectra were photographically recorded, a typical exposure time was 3s. The frames were photoelectrically digitized with the Optronics Microdensitometer and transformed into intensities.

This paper presents preliminary results of the reduction of one spectrum in order to see, whether a distinction between granular and intergranular line asymmetries is possible. The spectrum covers a spatial region of about 140 arcsec, the 906 scans have a spatial distance of 0.16 arcsec. The bisector curves were calculated for all four lines but in the blue wing of line I and in the red wing of line III also a terrestrial line was present. In order to avoid influences on the bisectors, we could only go to a lower intensity level than for lines II and IV.

3. RESULTS

The 906 scans in the region of 140 arcsec lead to the following preliminary results:

i. We could clearly measure the variation of the residual intensities in the bright and dark regions. This was not investigated further.

ii. There is a good correlation between the relative wavelength shift and the intensity. Bright structures (granules) show a characteristic blue shift with strong asymmetries.

iii. The bisectors of the spatially resolved spectra show no C-shape as has been known from spectra of the spatially unresolved Sun.

iv. The bisectors have both a red and a blue-asymmetry (Fig. 1, 2, 3).

Fig. 1 shows 30 spatially neighboring bisectors covering a region of 4.8 arcsec. The peak to peak velocity varies from the line core from 10 mÅ
(0.45 km s\(^{-1}\)) to 1 km s\(^{-1}\) at the line wings which confirms once again the decrease of the rms velocity fluctuation with height in the atmosphere.

Fig. 1: 30 spatially neighboring bisectors of the line 6494.944 Å covering a region of 4.8 arcsec.

v. For considering only the asymmetries we shifted in Fig. 2 and in Fig. 3 the bisectors of 100 line profiles covering a range of 16 arcsec to the same line core position. For the strongest line investigated a blue asymmetry of max 24 mÅ and a red asymmetry of 10 mÅ were obtained. For the weakest line the maximum blue asymmetry was 16 mÅ and the red asymmetry 6 mÅ.

vi. As is evident from the figures the blue asymmetries are remarkable larger than the red asymmetries. The blue asymmetries are of the same order found by Voigt, Schröter and Steffen. The red asymmetries are considerably smaller as one would have expected. This can be explained that the intergranular space is not sufficiently resolved. Wiehr (1987) claimed that the resolving power of the used spectrograph is 0.5 arcsec. For unambiguous measurements of line profiles in the intergranular space instruments with higher resolving power i.e. larger aperture will be necessary.

4. CONCLUSIONS

The presented preliminary observational results clearly demonstrate that with sufficient resolution there is a blue and a red asymmetry in the lines. These are considerably larger than for spatially unresolved spectra. This leads to the conclusion that the observed line asymmetry of
Fig. 2: bisectors of 100 line profiles covering a range of 16 arcsec.
Strong line 6494.944 Å

Fig. 3: bisectors of 100 line profiles covering a range of 16 arcsec.
Weak line 6494.499 Å
spatially unresolved spectra (C-shape) consists of more asymmetric profiles and not of symmetric profiles. Since there are now observations of sufficient spatial resolution a direct comparison between observations and model calculations should be possible.

5. REFERENCES

Discussion

RIGHINI — I suggest to superimpose line bisectors by taking as zero point in the wavelength scale that point which corresponds (via the response function) to the level where the correlation between the temperature fluctuation and the velocity fluctuation changes sign.

MATTIG — In this presentation we demonstrate only that the effects on the bisectors are remarkably more pronounced in the resolved spectra than in the unresolved spectra.

DRAVINS — What is your spatial resolution?

MATTIG — About 0.5 arcsec.

DRAVINS — Even if the spatial resolution in the spectra (in the half-width sense) is perhaps 0.5 arcsec, then the width at 10% or 20% must be at least about 1 arcsec. Both high-resolution images and detailed numerical simulations indicate the presence of significant structure down to a level of 0.1 arcsec. Since the observed line profiles are then spatial averages over some 100 different spatial elements, the observed line asymmetries may be largely a function of the spatial resolution, and perhaps not so much of e.g. the depth dependence of the velocity fields.

MATTIG — May be. I hope that we will have spectra with better resolution from the VTT in the near future. On the other hand, from measurements of the velocity fluctuations in different lines, we know that there is a strong depth dependence of the velocity field.

EDITH MÜLLER — None of the many bisectors you have shown, and have measured up to 10% of the continuum intensity, have a C-shape as found previously by various others. So you define the asymmetry given by a bisector as its largest extension, and then find values of up to 20 mÅ for the asymmetry. Is that right?

MATTIG — Yes, this is correct. That is the main difference between spatially resolved bisectors and the typical C-shape from unresolved line profiles.

EDITH MÜLLER — Let me comment: I have a PhD student at the University of Athens, Mrs. Mariella Stathopoulou, who has been studying the bisectors of a large number of iron lines determined on Kitt Peak FTS spectrograms observed at disk center, near the limb and in integrated solar light. At disk center, many lines have C-shaped bisectors and others do not, whereas at the limb only a few lines have C-shaped bisectors while most of the lines do not. Furthermore, the asymmetries show a clear dependence on the excitation potential of the lines. The bisectors of the lines on the integrated solar light spectrograms behave somewhat intermediate between the bisectors at the center and near the limb of the solar disk. So, according to your spatially resolved observations, our C-shaped bisectors would be a smearing over a number of differently extended and directed line bisectors.

DEUBNER — You have shown an impressive variety of line bisector shapes and a large enough scatter of their asymmetries to worry about. However, one should not forget that 10 mÅ corresponds to velocities not uncommon for p-modes. In
order to separate the effects of p-mode oscillations and of granular dynamics, one would certainly need time series of profiles at different positions with respect to the outlines of granules.

MATTIG — I agree completely with you and we will observe this as soon as possible. Here, I have concentrated on the line asymmetries and not on the line shifts. We assume that p-modes more or less produce shifts only, because of the small height gradient derived from the variation between different lines. Is 10 mÅ asymmetry really a representative value? It is not observed in spatially resolved spectra.

KNEER — I think that the line asymmetries shown here are mainly of granular origin and not due to oscillations, because the oscillatory velocity increases with height and thus with line depth (grossly). But here the extensions are largest in the wings of the spectral lines.

RIGHINI — Let me comment on that. We must keep in mind that due to phase effects, we have a drastic change of bisector shape during the oscillation.

STEFFEN — I think it is not quite fair to confront the results of my numerical simulations with the impression you get from the very simple, schematic illustration given by Dravins et al.\textsuperscript{1}. I wonder whether there is still a contradiction if you use the more detailed results from the granulation models of Nordlund et al.?

MATTIG — I have not compared our data with the models of Nordlund.

BECKERS — Steffen’s models also predict that regions on the sun with large red line asymmetry have also shallower lines. I do not see this in your measurements. Comment!

MATTIG — That is correct, but in this presentation we have only discussed the line asymmetries and not the line profiles in detail.

\textsuperscript{1}D. Dravins, L. Lindegren and Å. Nordlund, 1981, \textit{Astron. Astrophys.} \textbf{96}, 345.