Precise Stellar Radial Velocities
ASP Conference Series, Vol. 185, 1999
J. B. Hearnshaw and C. D. Scarfe, eds.

Differential Fe I Line Shifts as Convective Signatures in R = 40 000 Échelle Spectra?[1]

Dag Gullberg

Lund Observatory, Box 43, SE-22100 Lund, Sweden

Abstract. The convection in stellar atmospheres causes spectral lines to be more or less blue-shifted. The differential wavelength shift between two groups of spectral lines could be used to characterize the convection. This paper describes such an effort using cross-correlations between R ≈ 40 000 échelle spectra and laboratory wavelength templates.

1. Differential line shifts

Stellar surface convection causes spectral lines to become asymmetric and shifted in wavelength (see Dravins (1999) for a recent review). Even if the resolution and noise of an observed spectrum would prevent measurements of asymmetries in the lines, the shift of the entire line or, more interestingly, wavelength shifts between different classes of spectral lines might be measurable.

Differential shifts, i.e. the difference in shift between lines or groups of lines in a spectrum, have some observational advantages, as compared to finding the global spectroscopic radial velocity and comparing it with the corresponding astrometric radial velocity (Dravins et al. 1999; Madsen, Lindegren, & Dravins 1999). The differential shifts are independent of the radial velocity, drift in the wavelength zero-point (on time scales larger than exposure times), gravitational red-shift, etc. This is because it compares shifts *within* a spectrum, thus being indifferent to any global wavelength shifts. Only photospheric velocity fields that give rise to differential effects will be seen. Major requirements are that the observed spectrum has a high degree of internal wavelength scale integrity and good signal-to-noise ratio, and that the laboratory wavelengths are known to high accuracy.

Spectra from the Moon, the Hyades and Ursa Major group stars, several IAU radial-velocity standards and some other stars were obtained during 1997. The observations were made at Observatoire de Haute-Provence using the échelle spectrograph Elodie (Baranne et al. 1996) with R ≈ 40 000 and operating in the spectral range 389-680 nm.

[1]Data were obtained at Observatoire de Haute-Provence, France.

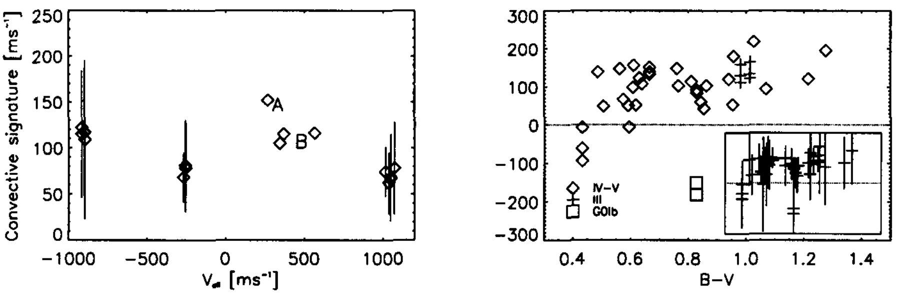

Figure 1. **Left:** The convective signature, *c.s.*, for the solar atlas (*A* and *B*) and the Elodie Moon observations. *A* is *c.s.* for the original solar atlas (R > 230 000), and *B* for the solar atlas made to mimic R = 30 000 - 50 000 spectra. **Right:** *c.s.* for a large part of the observation program. Note the inverted *c.s.* of the G0Ib star as compared to main sequence stars of same spectral type. Error-bars are not shown in the large diagram for clarity but, as is seen in the inset, the estimated errors are large.

2. Simulations vs Elodie

In solar-type stars, deep Fe I lines have, on average, less convective shift than shallow ones. To search for for differential shifts (between deep and shallow Fe I lines) in the data, synthetic correlation masks based on Fe I laboratory wavelengths were created for only deep and only shallow lines respectively, where the residual-flux breakpoint was 40% of the continuum in resolved solar flux spectrum. To test if it is at all possible to find anything in R $\approx$ 40 000 spectra, a high resolution (R > 230 000) solar atlas (Kurucz et al. 1984) was used as a test bed, being convolved with instrumental profiles that would mimic spectrographs of R = 30 000 – 50 000.

287 largely unblended Fe I lines were selected from the Nave et al. (1994) line list, divided into two subsets of 137 deep and 150 shallow ones. The software for Elodie data reduction, developed in-house, created synthetic templates based on the two subsets, and the simulated medium-resolution spectra were correlated with these templates, yielding separate velocities for the deep and shallow line groups. A differential velocity ($V_{\rm deep} - V_{\rm shallow}$), henceforth called convective signature (*c.s.*), of about 110 m s^{-1} results from this exercise. For the original solar atlas *c.s.* = 152 m s^{-1} (Fig. 1, left).

With some anticipation of what could be expected, the Elodie lunar observations were treated the same way. The weighted mean of the solar convective signature as found in Elodie data is 82 m s^{-1}, with an estimated error of typically 50 m s^{-1} for individual measurements and 15 m s^{-1} for the mean. The integrated signal of the shallow line dataset is small, resulting in quite large errors in those velocities, propagating into the error for the convective signature, as is seen in Fig. 1 (left). Comparing the Moon results with our simulated cases, it can be concluded that they appear to be similar.

3. Results using Elodie data

By applying the convective signature concept on a large number of stars in the observation program, we get a handle on how this works for different spectral types and luminosity classes. The results in Fig. 1 (right) show an inversion in the convective signature for F stars, as well as for one G0 supergiant, as compared to the Sun. This is compatible with bisector analyses found elsewhere in the literature. The granulation boundary for main-sequence stars is believed to be around F0 (Gray & Nagel 1989), although we see some indications of convective signature inversion beginning already for late F stars.

It appears that the G0Ib star (HIP 106 278, HD 204 867, an IAU standard star) has a distinctly different convective signature of -166 m s^{-1} with an estimated error of 150 m s^{-1}, based on two observations. This would suggest that the supergiant is on the early side of the granulation boundary with inverted C-shaped bisectors, as could be expected for a G0Ib star (Gray & Toner 1986). We get a convective signature for Procyon (F5IV-V) of -54 m s^{-1} with an estimated error of 80 m s^{-1}, based on three observations. More examples can be found in Table 1.

Table 1. Convective signature, *c.s.* and its standard error *s.e.* for some objects. The number of observations used to compute *c.s.* is *n*.

Star	Sp. Type	c.s. m s^{-1}	s.e. m s^{-1}	n
Moonlight	G2V	82	15	12
51 Peg	G2.5V	141	30	3
HD 204 867	G0Ib	-166	150	2
HD 27 371	G8III	134	40	3
HD 28 305	K0III	141	35	3
Procyon	F5IV-V	-54	80	3

Can we believe these results? The high sensitivity in the shallow line dataset to excursions away from solar type spectra makes early type stars in general very difficult, and those with large $v \sin i$ virtually impossible, to handle. The shallow lines simply fade away as we move towards increasing effective temperature. For many of these earlier stars we get information only for the deep dataset, if any at all, making it impossible to use only Fe I lines. Illustrating the problem, Fig. 2 shows the difference in Fe I line depths for an F5 and a K1 star (both quite slow rotators). On top of this, there is also the aspect of what we really are probing when using two sets of lines and applying them to different spectral types and luminosity classes. In the light of the above limitations, one should, at this stage, refrain from drawing conclusions on the apparent discrepancy in *c.s.* between 51 Peg and the Sun and the apparent similarities between 51 Peg and the two giants. However, the inverted (compared to the Sun) *c.s.* of the G0Ib and possibly also the negative *c.s.* for Procyon seem significant enough to be real.

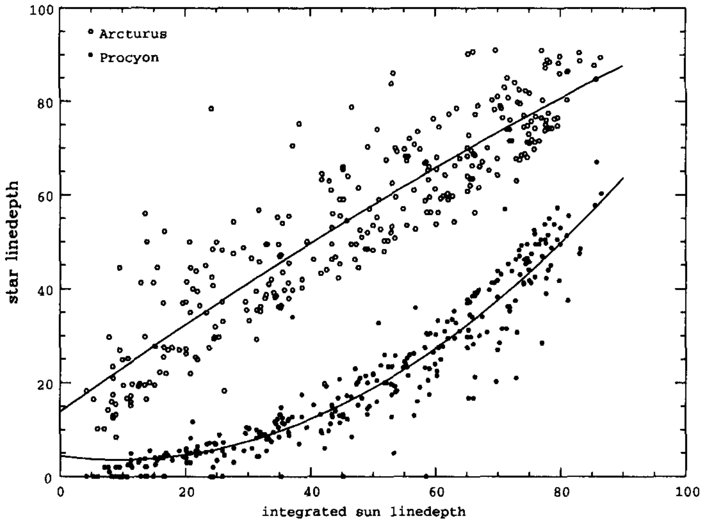

Figure 2. This diagram illustrates the difficulty in using Fe I lines at earlier spectral types, because the shallow lines rapidly disappear with increasing effective temperature (and large $v \sin i$) around F5, making it virtually impossible to compute the *c.s.* based on Fe I lines only. The plot shows 306 Fe I lines with $\lambda \in [436.6, 685.8]$ nm.

4. Future work

It is clear that, for this method to be useful in a wider spectral range, some creative thinking must go into optimizing the *c.s.* through the selection of line-sets. The optimization should be in the sense that a line-set pair selected properly map out the convection for the spectral types aimed for, with minimal errors. It will probably require 3D or 2D hydrodynamic simulations of granulation for different spectral types (Nordlund & Dravins 1990; Steffen, Ludwig, & Krüss 1989) to do this. Also, any line lists set up must have corresponding laboratory wavelengths with high accuracy available.

First steps, however, will be to increment the number of lines used, using also Fe II and other species for which there are available reasonably accurate wavelength lists. Also, the extraction of rough bisector shape information will be looked into closely for the data available, as complementary information.

References

Baranne, A., Queloz, D., Mayor, M., Adrianzyk, G., Knispel, G., Kohler, D., Lacroix, D., Meunier, J.-P., Rimbaud, G., & Vin, A. 1996, A&AS, 119, 373

Dravins, D. 1999, these Proceedings

Dravins, D., Gullberg, D., Lindegren, L., & Madsen, S. 1999, these Proceedings

Gray, D.F., & Toner, C.G. 1986, PASP, 98, 499

Gray, D.F., & Nagel, T. 1989, ApJ, 341, 421

Kurucz, R. L., Furenlid, I., Brault, J., & Testerman, L. 1984, Solar Flux Atlas from 296 to 1300 nm, Sunspot, New Mexico: National Solar Observatory

Madsen, S., Lindegren, L., & Dravins, D. 1998, these Proceedings

Nave, G., Johansson, J., Learner, R.C.M., Thorne, A.P., & Brault, J. W. 1994, ApJS, 94, 221

Nordlund, Å., & Dravins, D. 1990, A&A, 228, 155

Steffen, M., Ludwig, H.-G., & Krüss, A. 1989, A&A, 213, 371

Discussion

Hamilton: The Fe I lines do not have a uniform distribution of strength with wavelength; strong lines tend to be bluer. Could this have an effect on the calculated *c.s*? If so the wavelength and depth sensitivities are probably competing. Is there a way to include potential wavelength sensitivity?

Gullberg: Wavelength dependence of line depth has not been taken into account in this work so far. However, there is no problem in including any such constraints in the line selection in future work.