OSCILLATOR STRENGTHS FROM THE HIGH S/N SOLAR SPECTRUM

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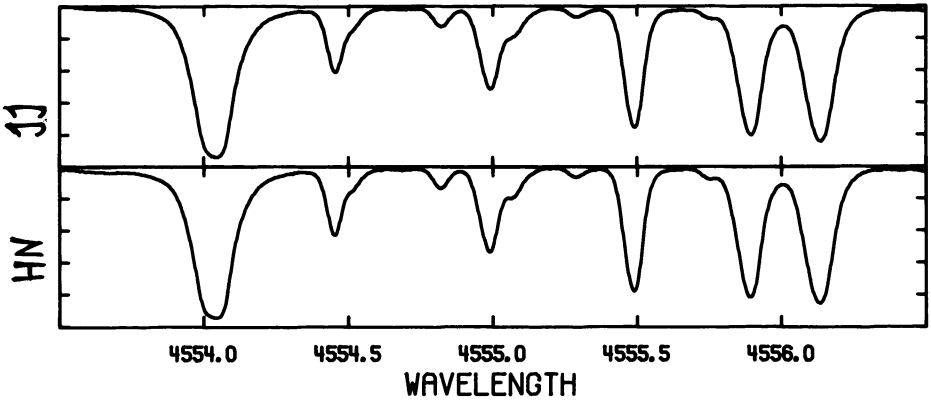
Most of modern solar physics is not concerned with high S/N spectrometry, but rather with high spatial resolution in narrow-band imaging as well as spectrometry, and with high Fourier resolution in helioseismology.

Nevertheless, atlases of the solar spectrum are still being made, of ever higher spectral purity including S/N ratio. Fig. 1 compares the latest disk-center intensity atlas (Neckel 1987, based on Kitt Peak Fourier Transform Spectrometer data) with the well-known Jungfraujoch Atlas (Delbouille et al. 1973). Such high-quality data are useful for sun-as-a-star calibrations of stellar radiative transfer methods, of stellar activity and granulation diagnostics, and of atomic parameters used in abundance determination. It is my task here to discuss an example of the latter: solar gf-values.

The classic example of deriving oscillator strengths by fitting solar lines is Holweger's (1967) thesis, more recently followed by Gurtovenko and Kostik (1981, 1982). Currently, these Kiev workers are preparing a solar gf compilation containing 2000 lines from 50 elements.

How precise are these solar gf-values? Let us briefly review the three major error sources: continuum errors, NLTE effects, and inhomogeneities. First the classical problem of continuum placement. Fig. 1 illustrates the rather arbitrary choices made in straightening and concatenating the short grating-spectrometer records of the Jungfraujoch Atlas. The third and fourth strips show the upper 5% of each atlas only, to display the continuum windows. The bottom strip shows their difference and represents a "Delbouille response function": it rather closely follows the 5-10 Å wide dips and humps present in the line connecting the highest HN peaks, implying that these were largely normalized away in the Jungfraujoch record adjustments. The broad-band HN continuum is not necessarily the "true" continuum either, but it has less adjustment noise in this frequency range. Such noise affects the determination of the "local" continuum from which line profiles should be measured if one does not go to the extent of full spectrum synthesis. In that case, the neglect of quasi-continuous opacities (unresolved blends, weak-line haze, overlapping

G. Cayrel de Strobel and M. Spite (eds.), The Impact of Very High S/N Spectroscopy on Stellar Physics, 367–371.



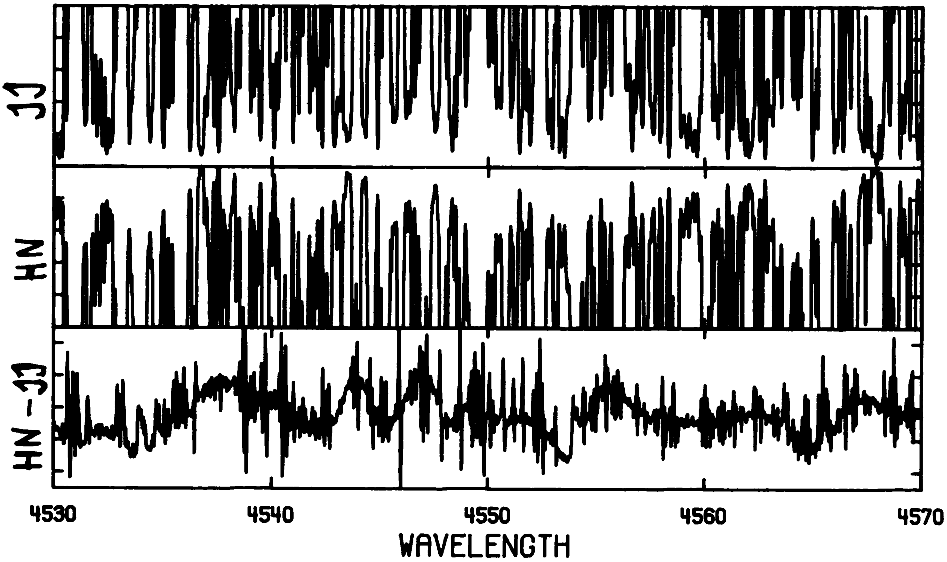


Fig. 1. Comparison of the Jungfraujoch Atlas (JJ) and the Hamburg-NSO Atlas (HN) of the solar disk-center spectrum. The higher resolution of HN is evident in the asymmetric core of Ba II 4554 and the blend of Cr II 4555. The third and fourth tracing show only the upper 5%, for JJ upside down. The asymmetry between them and their difference plotted at the bottom illustrate JJ normalization errors.

line wings) results in too small fitted gf-values because the computed line formation is located too deep, where the source function is steeper than at the actual height of formation. However, this deficit is partially cancelled by the steep inward decrease of the typical line-to-continuum opacity ratio. Solar modeling (Rutten and Van der Zalm 1984, Rutten and Kostik 1988) shows that for weak lines the error is typically halved: a 10% opacity deficit when fitting observed lines results in only a 5% (0.02 dex) gf underestimate. The error is much larger, however, if one measures from some "true" continuum or if one fits the depth of saturated lines.

The second issue is the effect of departures from LTE. These are usually neglected, but implicitly corrected for by assuming an LTE-masking model atmosphere based on LTE line fits (Rutten and Kostik 1982). The basic parameter is the steepness of the photospheric temperature gradient which sets the amount of NLTE overionization in the ultraviolet, and so affects the line optical depth scale even if the line source function obeys LTE (see Rutten 1988). Similarly, the often neglected overionization of hydrogen affects the continuum optical depth scale in the upper photosphere.

The temperature gradient is less steep in the newest Harvard modeling (Avrett 1985) than it used to be, because the inclusion of yet more Kurucz line-haze opacity has shifted the height of formation of the ultraviolet further outward, stretching the photospheric height scale. The empirical NLTE modeling has thus more or less retrieved the classical LTE Holweger-Müller (1974) model, and the predicted photospheric departures from LTE have become small. This is demonstrated in Fig. 2 for all clean solar iron lines: the differences between NLTE and LTE gf fits are indeed negligible (except for large-gf lines which have NLTE excitation, see Rutten 1988).

The third issue, inhomogeneities, provides the largest uncertainty. The solar granulation represents the dominant spoiler of the plane-parallel simplification for photospheric lines. Extensive supercomputer simulations by Nordlund (1984) lead to excellent fits of observed solar Fe I lines without invoking classical free parameters such as microturbulence, macroturbulence and damping enhancement factors. This is the first fudge-free reproduction of Fraunhofer lines! However, the lines fit only if the iron abundance (the only free parameter) is 0.4 dex below the standard value. This is a very important discrepancy. It arises because there is much neutral iron present in the cool intergranular lanes, and because spatial averaging differs from unresolved modeling because the ionization equilibrium is highly nonlinear in temperature.

The discrepancy would be yet larger (0.6 dex) if LTE would hold for the iron ionization equilibrium. It would also be larger if NLTE source functions had been adopted for the ultraviolet line haze, which contributes strongly to granular overshoot through radiative heating (Nordlund 1985).

In conclusion, solar gf-values for weak lines have better than 0.1 dex precision if one may trust plane-parallel modeling, even when assuming LTE. However, Nordlund's simulation of the solar granulation dramatically upsets this comfortable result.

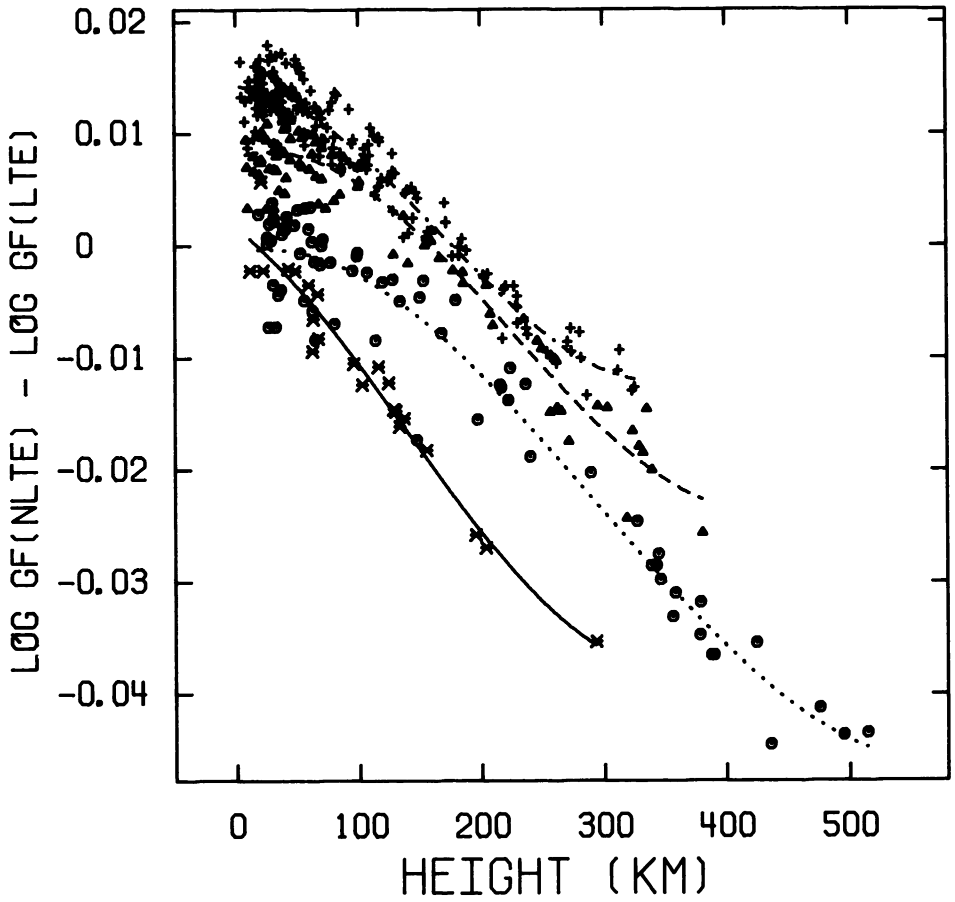


Fig. 2. Comparison of LTE and NLTE fits of the equivalent widths of all 254 Fe I and 22 Fe II lines in the solar clean-line list by Rutten and Van der Zalm (1984), against height of formation. NLTE fit: MACKKL model (Maltby et al. 1986), MACKKL turbulence, NLTE departure coefficients from Avrett (private communication). LTE fit: HOLMUL model (Holweger and Müller 1974), MACKKL turbulence. Fe II lines: asterisks, fitted with the solid curve. Fe I lines: split into low-excitation lines (circles, dotted fit), middle-excitation lines (triangles, dashed fit) and high-excitation lines (plusses, dot-dashed fit) as in Rutten and Kostik (1984). The separation of the various classes results from differences in the shape of the contribution function. The outward decrease results from model differences. The two descriptions are so close, however, that the differences shown here are negligible.

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DISCUSSION

GUSTAFSSON: The value of a correction to the solar iron abundance of -0.3 dex +0.1 dex, the second number being the correction for extra overionization, was confirmed in a recent private communication with Åke Nordlund. I think he would agree, however, that further calculations with existing solar simulations and corresponding plane-parallel models are necessary before this correction is well-determined.

RUTTEN: The 0.4 dex I quoted results from subtracting his published value (Nordlund 1984, $A_{Fe} = 7.18$) from my plane-parallel one (Rutten and Van der Zalm 1984, $A_{Fe} = 7.63$). NLTE overionization was included in both. However, I agree that more computations are necessary, especially on the effects of departures from LTE in the Kurucz line-haze opacities.