A METHOD FOR CALIBRATING, IN ABSOLUTE FLUX UNITS, CA II H PROFILES OF LATE TYPE STARS OBSERVED AT ESO

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ABSTRACT. In this paper we have applied to the Sun a method for calibrating, in absolute flux units, Ca II H profiles of late-type stars. After comparing, in the region 3948-3882 A, an LTE synthetic spectrum with the data of the solar flux Atlas by Kurucz et al.(1984), we have defined the wavelength ranges where observations agree with computations, based on specific radiative equilibrium models and collisional broadening parameters. By fitting in these regions the spectrum of the moon observed at ESO with the corresponding synthetic spectrum, we derived a calibration factor that enables us to calibrate, in absolute flux units, the whole observed range.

1. INTRODUCTION

In this paper we present the method that we will adopt for calibrating, in absolute flux units (10^6erg sec^{-1} cm^{-2} A^{-1}), a set of Ca II H profiles of stars of spectral type F2-K5 observed at ESO with high resolution. The stars are listed in Table I; the observations and the data reduction are described in Crivellari et al.(1987).

For late-type stars it is practically impossible to define a true continuum level in the region below 4000 A; therefore, only profiles that are absolutely calibrated can be compared with each other and with the computed ones, and can be used for deriving chromospheric radiative losses.

The problem of the calibration of the Ca II H region observed at ESO is by no means trivial, because the most widely used methods require either observations in the whole range 3925-3975 A (Linsky et al.,1979) or observations at 3950 A (Duncan,1981; Catalano,1979), where we suppose there is a pseudo-continuum level. The useful range of most of the observations in Table I is 3954-3985 A.

We therefore decided to apply the calibration procedure proposed by

G. Cayrel de Strobel and M. Spite (eds.), The Impact of Very High S/N Spectroscopy on Stellar Physics, 153–161.

Ayres et al.(1976). The observed wing profiles are calibrated with the absolute flux wing profiles computed with a radiative equilibrium (RE) model photosphere. This method is independent of the observed range and can at the same time give an estimate of the chromospheric radiative losses in the core of the line.

Because the procedure is model dependent, before applying it to the observed stars we tested it on solar data.

Table I: The observed stars.

HR	HD				Teff(K)	logg	N(H)	
77	1581	ζ Tuc	F9	V	5832	4.82	1	Q
88	1835	δ Cet	G2	V	5814	4.59	2	A
98	2151	β Hyd	G2	IV	5747	4.45	3	Q
509	10700	τ Cet	G8	V	4975	4.52	2	Q
591	12311	α Hyd	F0	V			1	Q
1084	22049	ε Eri	K2	V	4998	4.80	4	A
5459	128620	α Cen A	G2	V	5770	4.50	6	Q
5460	128621	α Cen B	K1	V	5300	4.54	7	Q
5544	131156	ξ Boo A	G8	V			4	A
5568	131977		K4	V			1	A
5897	141891	β Tr A	F2	III			1	Q
6094	147513		G2	V			3	A
6098	147584	ζ Tra	F9	V	6054	4.66	2	A
6102	147675	γ Aps	G8/K0	III	5050	3.10	1	A
6752	165341	70 Oph A	K0	V			4	A
7665	190248	δ Pav	G6/8	IV	5563	3.81	4	Q
7703	191408		K3	V	4903	4.54	2	Q
7776	193495	β Cap	F8+A0	V	4876	4.54	1	Q
8387	209100	ε Ind	K4/K5	V	4590	4.57	6	A
		Moon	G2	V	4770	4.44	2	

Q or A indicates whether the star is quiescent or active.
N(H) indicates how many observations of the CaII H profile have been made for each star.

2. THE DATA

The profile to be calibrated is the average of two observations of the solar light reflected by the moon. The spectra were obtained with CES plus the 1.4 m CAT of ESO. The resolution is $\lambda/\Delta\lambda = 8\ 10^4$. The two observations have been performed on 1/02/1985 and have an exposure time of 300 sec and 600 sec respectively; the useful range is 3954.592-3985.175 A.

3. THE CALIBRATION METHOD

Ayres et al.(1976) calibrated the observed K lines of αCen A and αCen B by fitting the far wing profiles ($\Delta\lambda > 5$A) with computed profiles based on radiative equilibrium (RE) models. The wing intensities for a particular RE model were calculated on the basis of an LTE partial coherent scattering formalism which considers a five-level representation of Ca II (Ayres,1975).

With ATLAS8 code (Kurucz,1986) we computed a RE line-blanketed solar model with parametrs Te=5770 K, log g=4.44, opacity distribution functions with 2 Km/s and mixing length to scale height ratio l/H=1. We want to stress that we have not considered specific empirical or semi-empirical solar models, but rather a theoretical model, because the calibration method should be generalized to the stars observed.

With the RE model we computed Ca II H profiles both in NLTE with the hypotheses of partial (PR) and complete redistribution (CR) and in LTE. We found that with the RE model adopted, without any increase in temperature in the upper layers, the Ca II H profiles computed in PR, CR and LTE do not show any remarkable difference. We conclude that with RE models we can use LTE to compute the photospheric CA II H profile that will be used to calibrate the observations.

4. TO WHAT EXTENT THE COMPUTED PROFILE IS RELIABLE

To test if the so-computed profile well represents the observed flux, we compared, in the region 3948-3982 A, the computed spectrum with the absolutely calibrated solar spectrum derived from the Solar Flux Atlas by Kurucz et al.(1984). The synthetic spectrum was computed only with the most important lines, namely Ca II K, Al I 3961.52, Ca II H and $H\varepsilon$. The result is that we cannot reproduce the whole extent of the Ca II H wings with the same Van der Waals parameter. Figure 1 and Figure 2 show the comparison between the profile of the Solar Atlas and the profiles computed with:

$$\gamma_{vw} = 1.7\ 10^{-8}\ NH(T/5000)^{0.3} \qquad \text{(Ayres,1975)}$$

and

$$\gamma_{vw} = 1.45\ 10^{-8}\ [NH + 0.42NHe + 0.85H2](T/10000)^{0.3}$$
(Kurucz and Avrett,1981)

where $1.45\ 10^{-8}$ is the Van der Waals parameter for pure hydrogen γ_H/NH computed with the tables of Deriddier and Van Rensbergen (1981). The radiative damping and the Stark broadening parameters for Ca II lines are $\gamma_{rad} = 1.5\ 10^{8} sec^{-1}$ and $\gamma_s = 3\ 10^{-6} Ne$ respectively (Shine and Linsky,1974). We adopted the Ca abundance $\log\varepsilon = -5.67$ (Lambert and Warner,1968) and a microturbulence $\xi = 1$Km/s. The use of the Bell et al.(1976) solar model gives results analogous to those of Figure 1 and Figure 2. The conclusion is that to obtain a reliable absolute calibration with the theoretical RE models available we should fit the

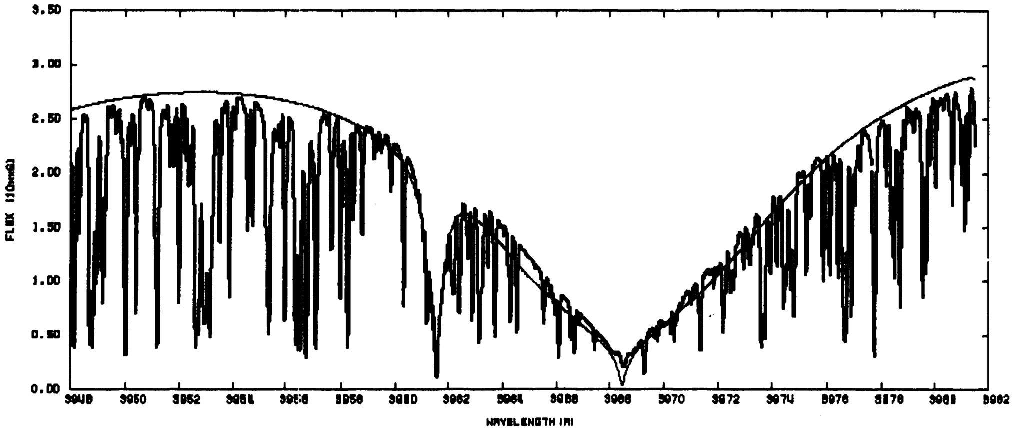

Figure 1. Comparison between the observed Ca II H profile from Kurucz et al.(1984) Solar Flux Atlas (thick line) and the profile computed with a RE Kurucz's model and γvw=1.7 10^{-8}NH(T/5000)$^{0.3}$ The units of the ordinates are: 10^{6}erg sec^{-1}cm^{-2}A^{-1}

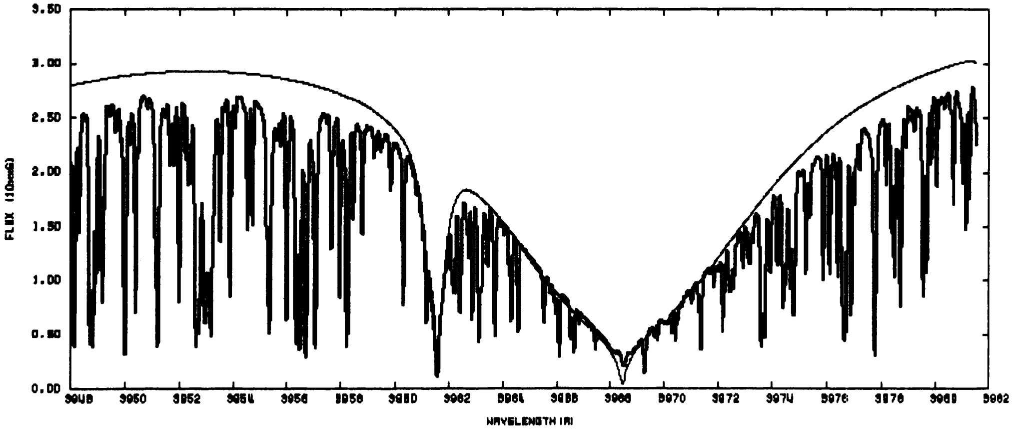

Figure 2. The same as Figure 1, but with
γ vw=1.456^{-8} [NH+0.42NHe+0.85NH2] (T/10000)$^{0.3}$

observed to the calculated spectrum only in appropriate wavelength ranges and with appropriate γvw parameters. Table II lists the useful wavelengths ranges and Van der Waals parameters for calibration purposes to be used with Kurucz's models (K models) or with Bell et al. models (BG models).

Table II: Useful wavelength ranges and Van der Waals parameters for calibration purposes.

Model	Van der Waals parameter γvw	wavelength ranges	
K	$1.70\ 10^{-8}NH(T/5000)^{0.3}$	3948-3958	3976-3982
K	$1.45\ 10^{-8}[NH+0.42NHe+0.85NH2](T/10000)^{0.3}$	3962-3967	3970-3974
BG	$1.45\ 10^{-8}[NH+0.42NHe+0.85NH2](T/10000)^{0.3}$	3948-3958	3975-3982
BG	$1.00\ 10^{-8}[NH+0.42NHe+0.85NH2](T/10000)^{0.3}$	3962-3967	3970-3973

5. THE ABSOLUTE CALIBRATION OF THE MOON SPECTRUM

To calibrate the ESO spectrum of the moon we have to fit the observed spectrum with the computed one and the closer the computed spectrum is to the observed one, the better the fit will be. Therefore, we computed a synthetic spectrum in the region 3948-3982 A with all the lines with residual flux in the line center $F_\lambda/Fc \leq 0.99$ predicted by either K or BG models. According to the model adopted and Van der Waals parameter chosen, we made the fit in the wavelength regions given in Table II.

If $Yc(\lambda)$ and $Yo(\lambda)$ are the calculated and the observed flux points and if $Yc(\lambda)=C\ Yo(\lambda)$, with C a multiplicative factor, the fitting procedure consists in deriving that C which minimizes the quantity

$$\chi^2 = \sum_{i=1}^{N}[Yc(\lambda)-CYo(\lambda)]^2$$

where N is the total number of points. We will call C the calibration factor.

As an example, if we adopt the K model and the Van der Waals parameter

$$\gamma vw=1.45\ 10^{-8}[NH+0.42NHe+0.85NH2](T/10000)^{0.3}$$

the fit has to be made in the regions 3962-3967 A, and 3970-3974 A, according to Table II. In this case the resulting calibration factor is $C=11.578\ 10^6$.

We obtain the whole Ca II H profile of the moon spectrum calibrated in absolute flux units by multiplying all the observed points by C.

Figure 3 compares the calibrated moon spectrum with the spectrum of the Solar Flux Atlas(Kurucz et al.,1984). Both spectra are in absolute flux units. The agreement is quite satisfactory. We obtained similar results for the other cases of Table II.

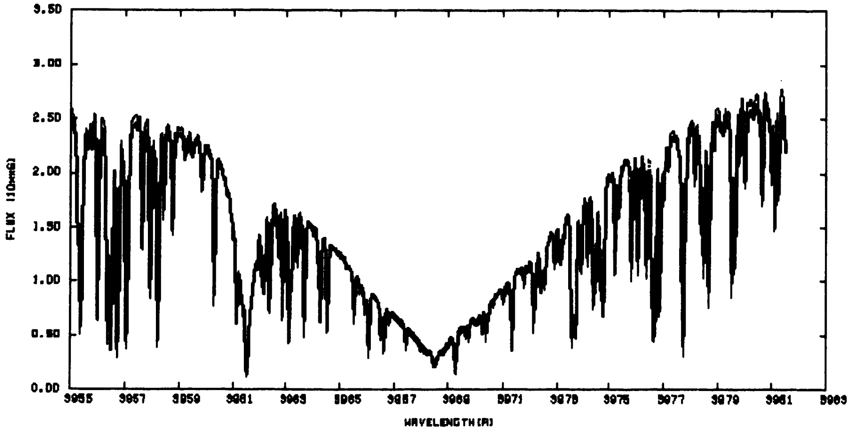

Figure 3.Comparison of the calibrated moon spectrum (thick line) with the profile in absolute flux units of the Solar Flux Atlas by Kurucz et al. (1984) (thin line). The units of the ordinates are 10^6erg $sec^{-1}cm^{-2}A^{-1}$.

Table III: Solar H1 indices obtained from different sources.

	$\mathfrak{J}$(H1)	$\mathfrak{J}'$(H1)	
1. Moon	3.9 10^5	2.0 10^5	This paper
2. Moon	3.7 10^5	2.1 10^5	Linsky et al.(1979)
3. Mean Sun	3.8 10^5	2.2 10^5	Linsky et al.(1979)
4. Sky	4.6 10^5	3.0 10^5	Linsky et al.(1979)
5. Sun	3.8 10^5	1.9 10^5	Beckers et al.(1976) Atlas
6. Sun	4.6 10^5	2.8 10^5	Kurucz et al. (1984) Atlas

The values in rows 5 and 6 have been measured directly from the Atlases.

6. THE CHROMOSPHERIC RADIATIVE LOSSES

Table III compares the solar H1 indices obtained from our calibrated data with those of other sources in the literature. For the definitions of $\mathcal{F}$(H1) and $\mathcal{F}'$(H1) see Linsky et al.(1979).

Our value agrees with those of Linsky et al.(1979) and with that derived from the Beckers et al.(1976) Solar Atlas. The values from the Kurucz et al.(1984) Solar Atlas and from the sky data of Linsky et al.(1979) are higher.

7. CONCLUSIONS

From the comparison of data already calibrated in absolute flux units (Kurucz et al. Solar Flux Atlas, 1984) with an LTE synthetic spectrum in the region 3948-3982 A we have seen that the adopted RE theoretical models for the photosphere are inadequate to reproduce the wings of the profile in the whole region. Nevertheless, in some ranges the computed flux matches the observed one, but, for a given Ca abundance, the regions differ with a different choice of the Van der Waals parameter. We can obtain a satisfactory calibration of the ESO data if we fit the observed spectrum to the computed one in the wavelength regions appropriate to the adopted model.

For stars different from the Sun, the major source of uncertainty for the proposed method would be, in our opinion, the values of the elemental abundances relative to the model parameters,Te, log g and microturbulence. In fact the existing quantitative analyses for the stars of Table I are mostly limited to curve of growth methods performed several years ago. For some stars, abundances for only a few elements are available. For a worthwile re-analysis of the photospheres of these stars, which is a necessary premise for a better understanding of the chromospheric properties, we need both obervations in large visual ranges with high resolution and a high S/N ratio, and more realistic blanketed models of cool stars, for instance with increased opacities.

In the meantime, we estimate that our analysis is the best we can do with the RE model method and with the available models and data. We have seen that it is valuable for the Sun. As a next step, we shall apply it to the stars of Table I.

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DISCUSSION

SNEDEN Did you use more than a few lines in your final synthetic spectra ?

CASTELLI Yes in my final synthetic spectrum I used about 380 lines for the region 3948-3982Å. These are all the lines with a residual flux in the line center $F\lambda/Fc<0.99$ predicted by the model.

SNEDEN How would you propose to add more lines (not yet identified) into your calculations?

CASTELLI In the CaII region there are only few unidentified lines . To add them in my calculations I have to wait that someone identifies them and provides the relative *gf* values.

GUSTAFSSON We cannot feel quite sure that the completeness of recent published line-lists is sufficient for this purpose. Which line-list did you use?

CASTELLI I used an extended and corrected version of the Kurucz-Peytreman line list. I continually update this list with the log*gf* values from the literature.

BAADE I believed I noted that, in all spectra you showed, the extreme blue wings (:blue ends of the spectra) were more depressed than the red wings are. CES spectra are known to suffer some vignetting at their blue end. Are you sure that this defect has been well compensated by your rectification procedure?

LINSKY Could you comment on how the scattered light at the CaII H and K lines is determined and substracted from the CES spectra? This is an important point for determining the absolute flux of the emission cores of the CaII lines because these features lie in the cores of very deep photospheric absorption lines.

CRIVELLARI Effects due to scattered light and vignettings are certainly present in CES spectra. As everybody, we are well aware of the problem and did our own measurements to estimate the percentage of the contamination of the signal. However we wish to stress that:

i- In our opinion the main source of contamination is the remanence effect in the RETICON (see Crivalleri and Foing, this proceedings).

ii- We think that, at this stage of the calibration work, the actual correction of the observed profiles is quite accurate for our purposes. One should also note that the comparison in the present paper is between a computed synthetized profile and the average spectrum of only two high quality observations of the solar light reflected by the moon (high S/N, low parasitic effect).