HOW PRECISE ARE SPECTROSCOPIC ABUNDANCE DETERMINATIONS TODAY?

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ABSTRACT. It is shown that a great breakthrough has occurred in the accuracy of spectroscopic abundance analyses with the introduction of solid state light detectors, such as Reticons and CCDs. Because of uncontrolled systematic errors in photographic photometry, abundances derived from high dispersion photographic spectra can hardly be known with an accuracy better than 0.3 dex. This is well exemplified by the recent finding that the observational scatter is large even in the equivalent widths of the Utrecht Solar Atlas. A fortiori these uncertainties are present in the [Fe/H] stellar abundance Catalogue, chiefly based in its present form on photographic material. For the future the calibration of the [Fe/H] Catalogue with spectra taken with Reticon detectors is recommended. A signal/noise ratio of 300 to 500 is more important than an improvement in spectral resolution with a low signal/noise ratio. Then, the remaining uncertainties in the abundances will mostly reflect inaccuracies in atmospheric parameter determinations of the models and in the assumptions underlying model computations.

1. INTRODUCTION

At present the impact of chemical abundance results on almost all the other branches of astrophysics is very important. You can hardly attend a meeting without assisting in an animated "coffee break" discussion between partisans of a high helium abundance (Y = 0.28) and partisans of a low helium abundance (Y = 0.23) in the present interstellar medium. Another hot discussion can be heard between believers that all globular clusters have the same helium abundance and those who do not. This latter group can again be divided in two subgroups: subgroup I believes that in globular clusters the abundance of helium is correlated with the abundance of metals; subgroup II believes that in some globular clusters the abundance of helium is anticorrelated with that of metals. Coming to abundance problems in stars nobody can testify better than myself about the great quantity of ink which has been spilled in writing papers and counter-papers on the

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existence or not of a super-metal-rich (SMR) population in our own and in other galaxies.

Abundance determinations are also the cornerstone of the study of atomic or turbulent diffusion in stellar envelopes. They provide important clues about stellar interiors, such as the study of the depletion of lithium along the main sequence of open clusters undertaken by Duncan and Jones (1982) and by ourselves (Cayrel et al. 1984). Even cosmology is linked to abundance determinations with the well known argument about the primordial elements left behind by the Big Bang. F. and M. Spite (1982) have recently discovered that lithium is still present in the atmospheres of the halo dwarfs hotter then 5600° K. The exact determination of the abundance of lithium in these extreme halo stars has a strong cosmological implication supporting a low density Universe ($\rho_B = 1.5 \times 10^{-31}$ g cm^{-2}). This density is in good agreement with the density deduced from the abundance of deuterium and favors an open Universe. So, those people who do not like the idea of living in a closed Universe may be very happy. These are a few examples of the present interest in abundance determinations but above all, research on abundances in stars and in the interstellar medium is important in the determination of the chemical evolution of our Galaxy and to a larger extent in that of the Universe.

Only very recently in the history of astronomy have abundance studies become fashionable. Table I contains an exhaustive list of meetings on abundance problems set up by the international body of astronomers. The first IAU Symposium dedicated exclusively to abundance determinations in stellar atmospheres was held in 1964. Between the first IAU Symposium in 1953 and the 26th Symposium nobody claimed that

TABLE I

CONFERENCES ON STELLAR ABUNDANCES

1953	Co-ordination of Galactic Research (IAU Symposium No. 1)
1964	Abundance Determinations in Stellar Spectra (IAU Symposium No. 26)
1970	Symposium on the Nuclear History of the Galaxy to honor the 60th Birthday of J. Greenstein (unpublished)
1975	Abundance Effects in Classification (IAU Symposium No. 72)
1980	ESO Workshop on Methods of Abundance Determination for Stars
1981	Cambridge (UK) Workshop on Arcturus (summarized by Trimble and Bell 1981)
1982	Systematic Effects in Abundance Determinations for Metal Poor Stars (held during the XVIII IAU General Assembly and published in the Publ. Astron. Soc. Pacific; see Bonsack 1983)

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it was necessary to have chemical abundances discussed during an IAU meeting. Part of this lack of interest during the first half of our century in spectroscopic abundance studies was due to the fact that no difference was found in chemical abundance between the Sun and the first stars analyzed in detail. Indeed, the first stars analysed in detail by Unsöld and coworkers, by K. O. Wright and R. Cayrel were mostly B and A dwarfs and giants, which undoubtedly represent a nearly perfect specimen of solar composition Population I stars. Therefore a very strong belief in the uniform chemical composition of the Universe arose among astrophysicists at the end of the forties. We had to await the discovery by Greenstein in 1957-59 of a metal deficiency by factors between 100 and 200 in globular cluster stars to become aware of large abundance differences between old and young stellar populations. As we can see on Table I, chemical abundances have since then been discussed far and wide, and because our Symposium deals with calibrations we may contribute to it by presenting some very good abundance data in a sample of well chosen stars.

I shall not speak during my talk about specific calibration problems so much as the comparison between sets of equivalent widths of standard stars taken with different spectrographs. Several years ago I inherited from K. O. Wright the chairmanship of a subcommission of Commission 29 dealing with line intensity standards. I have to confess that I let it die out because I could not impose a discipline upon the users of standard stars.

Even though the calibration of photometric abundances with spectroscopic results is of fundamental importance I shall not discuss it, either. I dedicated a paper to it during the ESO Workshop on Abundances in 1980 (Cayrel de Strobel 1980). What I shall now discuss are abundance results derived from high resolution spectroscopy. In Section 2, I shall compare Reticon spectra with photographic spectra and in Section 3, I shall discuss the relationship between spectrophotometric accuracy and the accuracy of abundances based on Reticon observations. In Section 4 I shall present the new edition of the [Fe/H] Catalogue and in Section 5 I shall give the conclusions.

2. RETICON SPECTRA VERSUS PHOTOGRAPHIC SPECTRA

One of the greatest breakthroughs in high resolution spectrography has been the development of efficient, wide-dynamic-range solid state imaging devices such as Reticon photodiode arrays. They enable the accurate measurement of lines on the part of the curve of growth which is still nearly linear. Indeed, high dispersion spectroscopic analyses remain the only primary method for deriving heavy element abundances in stars.

The visibility of a weak spectral line, i.e., its emerging from the noise of the spectrum, does not depend only upon the signal to noise

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ratio, S/N, of the spectrum on which we want to measure the line. We shall now discuss the coupling between resolution and S/N with the help of the spectra of standard stars taken with different spectrographs and different detectors. Table II shows S/N ratios and resolutions measured on photographic, electronographic and Reticon spectra. This Table is divided into six columns. Column 1 gives the name of the telescope, spectrograph, and detector with which the spectrum has been taken; Column 2 gives the name of the object, the identification number of the spectrum, when available, or the year in which the spectrum was taken, the apparent magnitude and spectral type of the object. Column 3 indicates the S/N ratio measured in three very clean windows: A, B, C in the spectrum of each object. Please note that the windows of the photographic, photoelectric and electronographic spectra are not the same as the windows of the Reticon spectra which are taken in a redder region of the spectrum. From this Table we can follow the evolution of the S/N ratio achieved on the same object at about the same spectral resolution i.e., ~0.22 Å. Around the years 1969-70 we wanted to begin a detailed analysis of a solar type dwarf in the Hyades. We choose for this purpose the 8.1 mag. dwarf VB64. As we can see we get a spectrum having a S/N ratio of about 3/1 with the OHP 152 Coudé on IIa 0 plates in 6 hours and 30 minutes. Needless to say, we did not begin a detailed analysis of VB64. We did better in 1975 with the Lallemand electronographic Camera, obtaining a spectrum of VB64 in 4 hours having a signal/noise ratio of about 30/1 on the same 152 Coudé telescope. We observed VB64 again with the Reticon on the Canada-France-Hawaii (CFH) Telescope in 1980 and 1981 and we obtained on the average a S/N ratio of 250/1 to 300/1 in about 2 hours exposure time. This was the beginning of our era of Reticon spectroscopic observations. Since then, we also have obtained excellent Reticon spectra from the Coudé Auxilliary Telescope (CAT) at ESO.

TABLE II

COMPARISON OF SIGNAL/NOISE RATIOS OBTAINED WITH DIFFERENT DETECTORS

TELESCOPE, SPECTROGRAPH, DETECTOR	OBJECT	INDENT.	V	SP.	S/N A	S/N B	S/N C	DISP. (Å/mm)	RES. Å	EXP.
152 Coudé OHP	Sun(Moon)	4390	-	G2 V	17	21	15	12.4	0.27	0h 07m
	Sun(Moon)	4391	-	G2 V	14	24	16	12.4	0.27	0 08
IIaO plates	Sun(Moon)	4398	-	G2 V	12	15	18	12.4	0.27	0 05
	HD76151	4369	6.0	G3 V	27	19	21	12.4	0.27	0 50
	HD76151	4377	6.0	G3 V	17	13	18	12.4	0.27	1 08
	HD76151	4395	6.0	G3 V	20	19	23	12.4	0.27	1 30
	VB64	-	8.12	G2 V	~3	~2	~4	12.4	0.27	6 30
152 Coudé OHP	Sun(Moon)	CE 682	-	G2 V	36	24	21	7.0	0.15	0 01
Electr. Camera	HD76151	CE 684	6.0	G3 V	49	28	17	7.0	0.15	1 00
Definix Plt.	VB64	CE 680	8.12	G2 V	29	41	23	7.0	0.15	4 00
Mt. Wilson photograph	Sun (Utrecht)		-26.7	G2 V	218	70	155	0.33	0.06	-
Sac. Peak photoelect.	Sun (Beckers)		-26.7	G2 V	304	84	172	0.20	0.02	-
Mt. Wilson photograph	Procyon (Griffin)[2]		0.38	F5IV-V	124	132	154	1.5	0.03	-
Mt. Wilson photograph	Arcturus (Griffin)		-0.04	K1 III	116	95	99	1.5	0.03	-
CFHT	Sun(Moon)	1980	-	G2 V	460	280	630	4.8	0.23	0 05
	Sun(Moon)	1981	-	G2 V	380	400	400	4.8	0.23	0 05
Coudé + image slicer	HD1835	1980	6.39	G2 V	-	160	270	4.8	0.23	0 30
+ 1872 pix. Reticon	ε Vir	1981	2.83	G8 III	480	360	420	4.8	0.23	0 05
	VB64	1980	8.12	G2 V	280	270	240	4.8	0.23	2 20

Another achievement was the installation of a holographic grating at Canada-France-Hawaii Telescope. The first Reticon spectra we have obtained with this grating are excellent and they combine high S/N ratio with high resolution (0.1 Å). As an example, CFH Reticon tracings of five stellar spectra are presented in Fig. 1. These tracings belong (from the bottom) to two **Hyades** dwarfs, to two Halo dwarfs and to the Moon. The first four stars are all fainter than 8th mag. The tracings of the spectra are very compact because they show the whole 133 Å large Reticon spectrum region. The spectra were obtained with the cooled Reticon array of 1872 photodiodes with 15μm wide pixels. With the 830 groove mm^{-1} mosaic grating the effective dispersion is 71 mÅ per pixel and the resolution (FWHM of the instrumental profile) is between 0.20 and 0.25 Å.

The five stars of Fig. 1 are all early G type stars, but whereas the spectra of the Hyades dwarfs very much resemble that of the Sun, the spectra of the Halo dwarfs are typically very weak-lined. The most interesting feature in these spectra is the presence, absence or weakening of the lithium line at 6707.8 Å. The reason Li is stronger in VB73 is that this star is somewhat hotter than VB64 and therefore its convective zone is shallower and lithium burning in this star is less important (Cayrel et al. 1984). In an analogous way we can explain the presence of Lithium in one Halo star, HD 194598, and its absence in the other (Spite and Spite 1982).

We usually took Reticon spectra centered at H_α, 6750 and 8550 Å for each program star. The H_α line was our criterion of effective temperature and the Ca II triplet was our criterion of chromospheric activity. The spectral region centered at 6750 is very interesting because besides the 6707 Li I doublet it also contains many weak and very weak Fe I lines. The spectral regions cited above are shown in Fig. 2 for the visual binary ξ UMa. In the Bright Star Catalogue both components of ξ UMa have the same spectral type: GO V (V=4.944 mag.). But in comparing the tracings of each spectral region we see that the spectra of the two components are not exactly the same: ξ UMa A is slightly hotter than ξ UMa B (the H_α profile is more developed and neutral FeI lines are weaker in ξ UMa A). From the two H_α profiles and, more importantly from the two visible components of the Ca II triplet we also see that the chromospheric activity of ξ UMa A is less pronounced than that of ξ UMa B. Very puzzling is the fact already noted by Duncan (1983), that contrary to what is expected the more active component does not show the lithium line at 6707 Å. We are carrying out a detailed analysis of ξ UMa and we shall try to understand the whys and the wherefores of this absence.

Bruce Campbell, Roger Cayrel and myself have already taken Reticon spectra (principally at CFHT but also at ESO) of main-sequence solar type and later stars of the Hyades, Pleiades and of the Ursa Major stream. The magnitudes of the Hyades stars were 8 to 9 mag., those of the Pleiades stars 10 to 11 mag., and the Ursa Major stars were 6 to 8 mag. stars. We worked on two other projects: bright field solar analogs

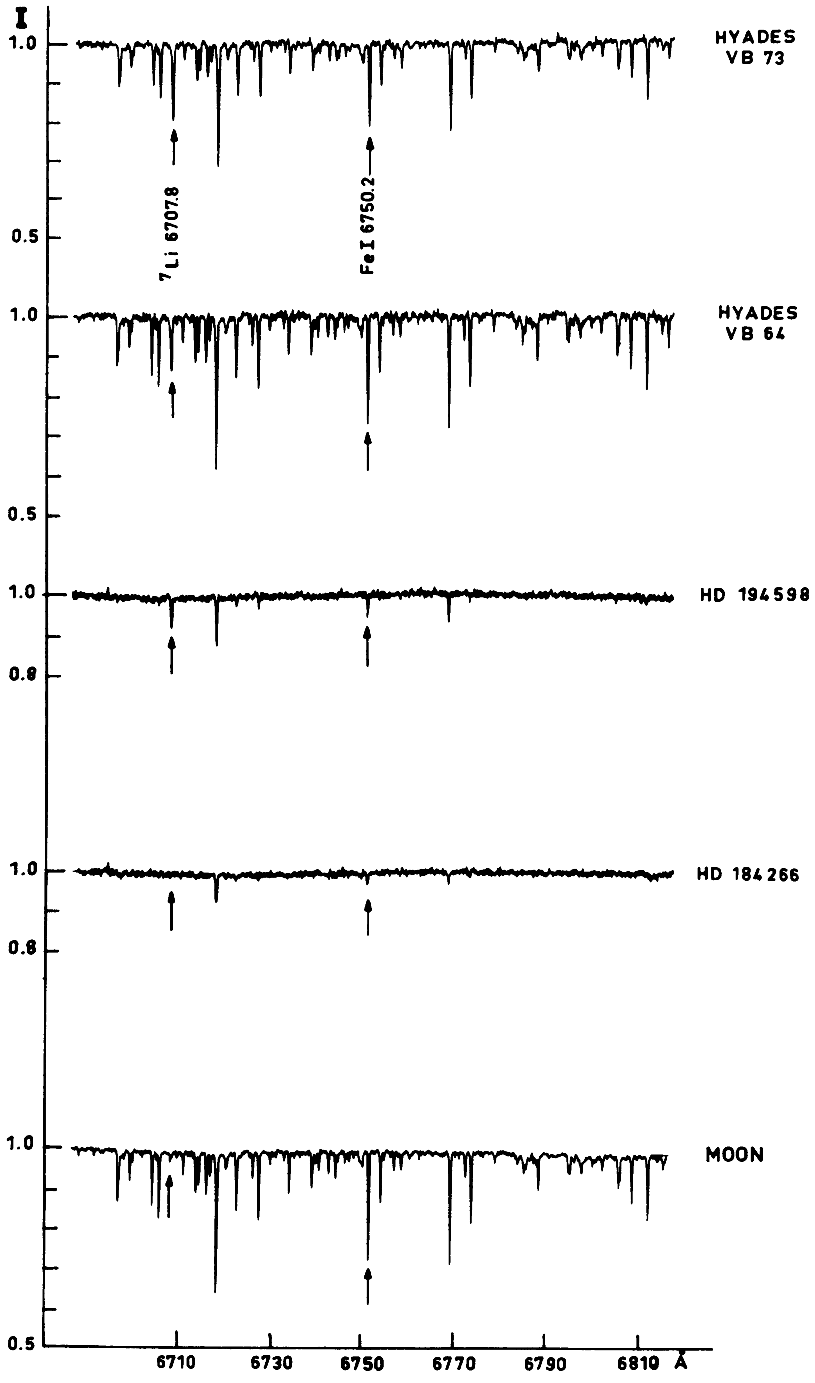

Fig. 1. Comparison of Reticon CFHT spectra of two Hyades and two Halo solar dwarfs. The Moon is taken as comparison object. Please note the presence of the resonance ^{7}Li line at λ6708 Å in the two Hyades dwarfs and in the Halo dwarf HD 194598.

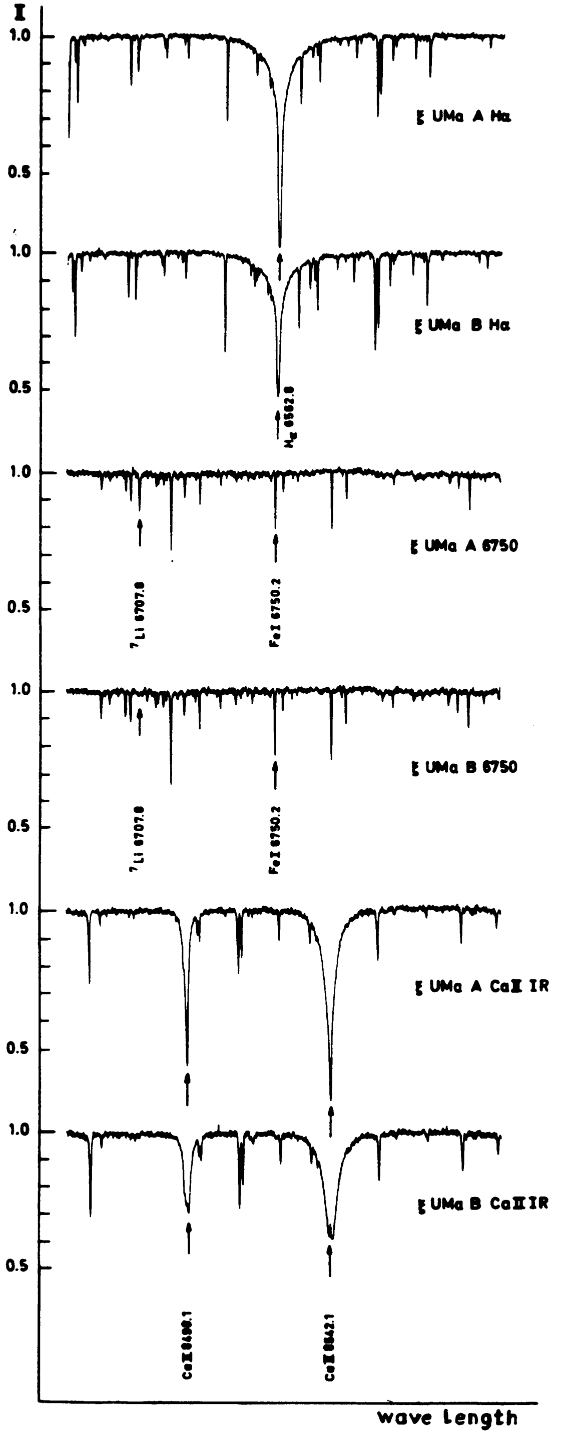

Fig. 2 CFHT Reticon spectra centered at H_α at λ6750 Å and at λ8550 Å of the visual binary ξ UMa.

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and bright SMR candidates. We also observed at ESO high parallax stars which have not yet been submitted to a detailed analysis. Up to now only one project has really been carried out: 12 Hyades solar dwarfs (11 cluster stars and one moving group star) have been analyzed in detail. For these stars we have determined differentially the abundance of iron relative to the Sun and with a lesser accuracy the abundance of other metals. Spectra of the Moon and Ceres have been obtained as comparison objects. This differential technique avoids the use of oscillator strengths.

Accurate measurements of lines weak enough to be on the nearly linear part of the curve of growth have been obtained. Equivalent widths were determined by detailed line profile fitting with special attention to the placement of the continuum and to contamination by blends of weak lines. Temperatures relative to the Sun were derived from the profile of H_α for the seven hottest stars. This procedure avoids the uncertainty of the solar color. For the four coolest stars (V-K) and (V-I) colors have been used after calibration of the indices through the H_α observations. The 12 program stars being all unevolved dwarfs, the gravity was taken to be equal to log $g = 4.5$. We have used a grid of flux constant line blanketed model atmospheres kindly provided by Bengt Gustafsson (1978). Stark broadening and self-resonance broadening for the theoretical H_α profile have been calculated following Vidal, Cooper and Smith (1971) for Stark broadening and Cayrel and Traving (1960) for self resonance broadening.

The details of the spectroscopic analysis of the Hyades dwarfs are given in the paper we have just finished writing on this subject (Cayrel, Cayrel de Strobel and Campbell 1984). From this paper are taken a few tables and figures concerning photometric data (Table III), equivalent width comparisons (Fig. 3 and 4), comparisons between observed and theoretical H_α profiles (Fig. 5,6,7, and 8), a few examples of curves of growth (Fig. 9,10,11, and 12), a table (Table 4) containing the atmosphere parameters: effective temperature, gravity, micro-turbulence and iron abundance [Fe/H], and a diagram of [Fe/H] vs. T_{eff} (Fig. 13). The last column of Table 4 gives the error in the mean of the iron abundance. This error is very small particularly for the first five stars, in which it is 10 times smaller than the error usually attributed to a metal abundance determination. In the next section, we shall discuss the influence of a high signal/noise ratio on the abundance determination of stars.

3. FROM SPECTROPHOTOMETRIC ACCURACY TO ABUNDANCE ACCURACY

This paper could have been called: "How precise are equivalent widths today?" This title would have been less ambitious but the goals are equally as important. Without precise equivalent widths of the weak lines we cannot pretend to know accurately the abundance of the chemical elements. Therefore we first have to discuss the spectrophotometric

TABLE III
Photometric data of observed Hyades dwarfs

HD number	VB	m_V	Sp. type	$B-V^{(1)}$	$B_2-V_1^{(2)}$	$(G-I)_6^{(3)}$	$(V-I)_{10}^{(4)}$	$(V-K)_{10}^{(4)}$
28344	73	7.85	G1V	0.60	0.350	-0.16	0.79	1.42
28992	97	7.94	G1V	0.63	0.359	-0.14	0.82	1.46
27859	52	7.80	G1V	0.60	0.343	-0.16	0.86	1.48
1835		6.39	G2V	0.66	0.398	-	-	-
28099	64	8.12	G6V	0.66	0.396	-0.12	0.89	1.54
27685	39	7.86	-	0.68	0.415	-0.09	0.93	-
26756	17	8.46	G5V	0.70	0.408	-0.04	0.93	1.64
28805	92	8.66	G8V	0.74	0.447	-0.02	0.96	1.70
27732	42	8.86	G9V	0.76	0.453	-0.01	1.01	-
+21°612	21	9.15	K0V	0.82	0.499	+0.06	1.05	-
+17°734	79	8.96	K0V	0.83	0.508	+0.11	1.06	1.88
27771	46	9.11	K1V	0.87	0.533	+0.12	1.13	1.93

(1) from Nicolet (1978) (3) from Sears and Whitford (1969)
(2) from Rufener (1980) (4) from Carney (1982)

accuracy of the equivalent widths we have obtained and then the error of the abundances we have derived. If one observes with a signal/noise ratio, S/N, i.e. a photometric accuracy $\varepsilon = N/S$, with a detector having a pixel size $\delta\lambda$, then what is the photometric accuracy achievable in the measurements of the equivalent width, W, of a weak line? A good order of magnitude estimate can be obtained by considering that the equivalent width,

$$W = \int \frac{F_c - F_\lambda}{F_c} \, d\lambda,$$

is obtained by taking the difference of the flux integrated over a band width $n\delta\lambda$ in one small spectral interval without lines (continuum measurement) and in one containing only the line to be measured:

$$W = \frac{1}{F_c}\left(\int F_c d\lambda - \int F_\lambda \, d\lambda\right) \simeq \frac{1}{F_c}\left(\sum_i^n F_i - \sum_j^n F_j\right).$$

The F_i and F_j are the individual fluxes for each pixel, the index i is taken to cover the continuum interval and the index j is taken to cover the line interval. Because the errors on all F_i and F_j are independent, the expected error on the parenthesis is $\sqrt{2n}\cdot\delta F$ if each flux is measured with the accuracy, $\delta F \simeq \varepsilon F_c \, \delta\lambda$. The relative error of F_c is much smaller because there is no destructive effect by difference on this factor, so one has for a weak line:

$$\delta W \simeq \sqrt{2n}\,\left(\frac{\delta F}{F_c}\right) \simeq \sqrt{2n}\;\varepsilon\delta\lambda \simeq \frac{\sqrt{2n}\;\delta\lambda}{S/N}.$$

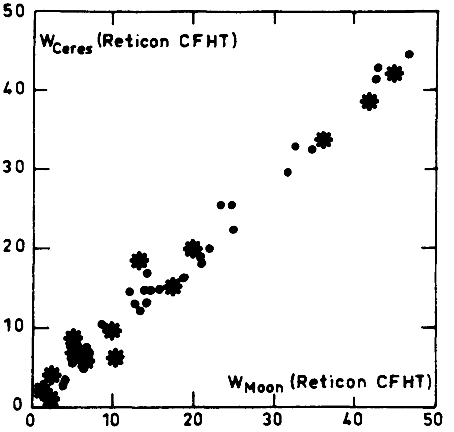

Fig. 3. Comparison of solar equivalent widths from CERES CFHT Reticon spectra and solar equivalent widths from MOON CFHT Reticon spectra. Dots: Fe-lines, asterisks: other elements. The equation of the regression line is: $W_{Ceres} = 0.94\ W_{Moon} + 0.86$. The correlation coefficient is 0.991.

In practice if $n \simeq 4$ to 6 the absolute error on W is about 3 times the pixel size divided by the S/N ratio. With $n = 5$, $S/N = 250$ and $\delta\lambda = 0.072$ Å the formula gives:

$$\delta W \simeq \frac{\sqrt{10}}{250} \times 0.072\ \text{Å} \simeq 0.001\ \text{Å or 1 mÅ}.$$

We have actually checked this order of magnitude with our spectra of Hyades dwarfs, estimating δW independently by taking the r.m.s. of the difference of the W's of several spectra of the same object. We found

$$\sigma = \delta W_{\text{observed}} = 1.7\ \text{mÅ}.$$

The agreement is not bad if one considers that in addition to the purely photometric error, which amounts to 5% for a 20m Å line at a S/N = 250, one should add an error which is much more difficult to estimate. This error comes from the fact that it is not true that the band used for measuring the continuum is free of lines, nor is it true that the band used for measuring the weak line contains only that weak line. A simple inspection of Delbouille (1973) and Rowland (1966) solar atlases (or the atlas for the integrated solar spectrum of Beckers et al. (1978)) shows that there are very weak unidentified lines everywhere making the position of the continuum uncertain at the level of a few parts per thousand. A 0.25% difference in the location of the continuum for the two bands produces an additional:

$$0.0025 \times n \times \delta\lambda = 0.0009 \text{ or } 0.9\ \text{mÅ}$$

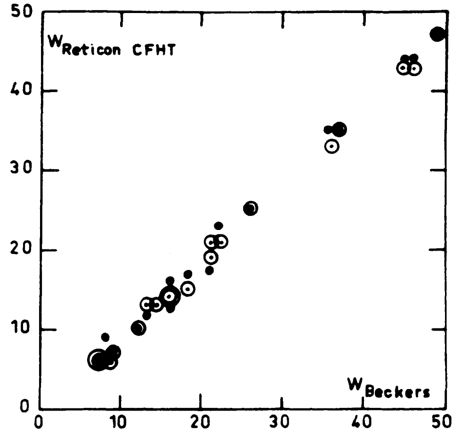

Fig. 4. Comparison of solar equivalent widths from CFHT Reticon spectra and solar equivalent widths from Beckers et al. (1976). Dotted circles: MOON, dots: CERES. The equation of the regression line is: $W_{CFHT} = 0.95\ W_B - 0.18$, and the correlation coefficient is 0.993.

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error, which is of course included in our empirical determination of δW. This makes the total random error of the equivalent width more like the experimental value: 1.7 mÅ than the theoretical value 1 mÅ.

The next step is to translate the error in the equivalent width into the error in the calculated abundance. As the absolute error δW is independent of W the relative accuracy first increases with W until the effect of the slope of the curve of growth and the uncertainty in which curve of growth to use (uncertainty in microturbulence and damping) produces an opposite effect. In our case this accuracy is best for a 20 mÅ line for which the slope of the curve of growth is about 0.8 and the effect of the uncertainty in microturbulence and damping is still small. In practice one sees from Table IV that the average standard deviation is about 0.07 dex (17%) on the abundance derived from a single line at S/N = 250 (see column σ_1). One should note that with a spectrum having a signal/noise ratio of 50 instead of 250 the error of 1.7 mÅ is going to become something like 6 mÅ moving the best equivalent widths further up and degrading the standard error to 0.2 dex or so.

A second source of error limiting our knowledge of abundances is in the inadequacy of the model atmospheres used in computing the lines for disentangling the effects of variations of effective temperature, gravity and general metallicity from genuine abundance effects. A golden rule to observe is to use an homogeneous grid of stellar atmospheres to do this, and not to use models of different origin for the two stars to be compared (the analyzed and the comparison star).

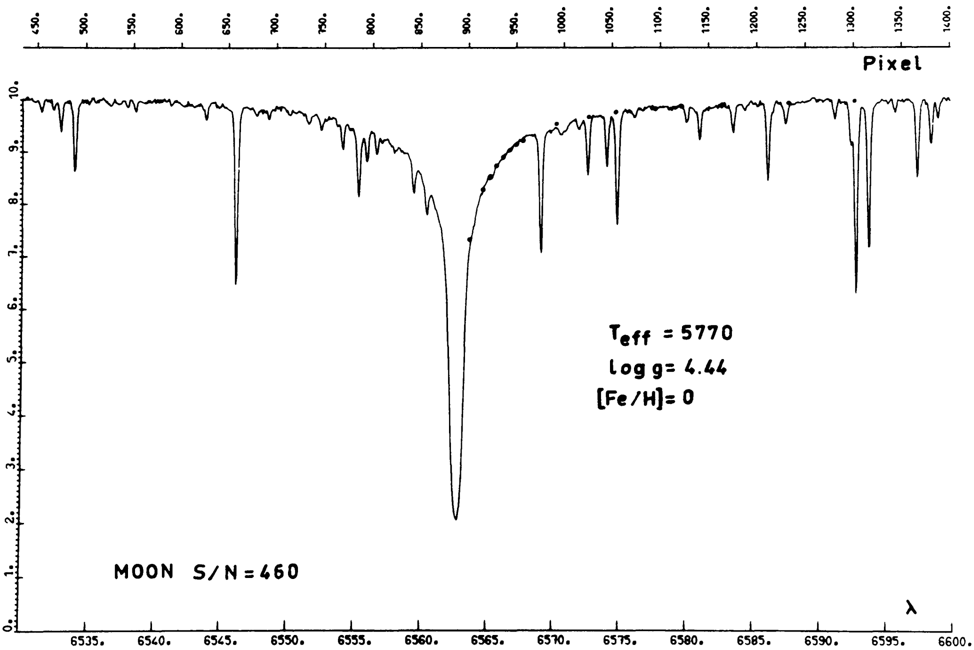

Fig. 5. CFHT Reticon spectrum of the H_α region of the Moon; dots represent a computed profile for the Sun.

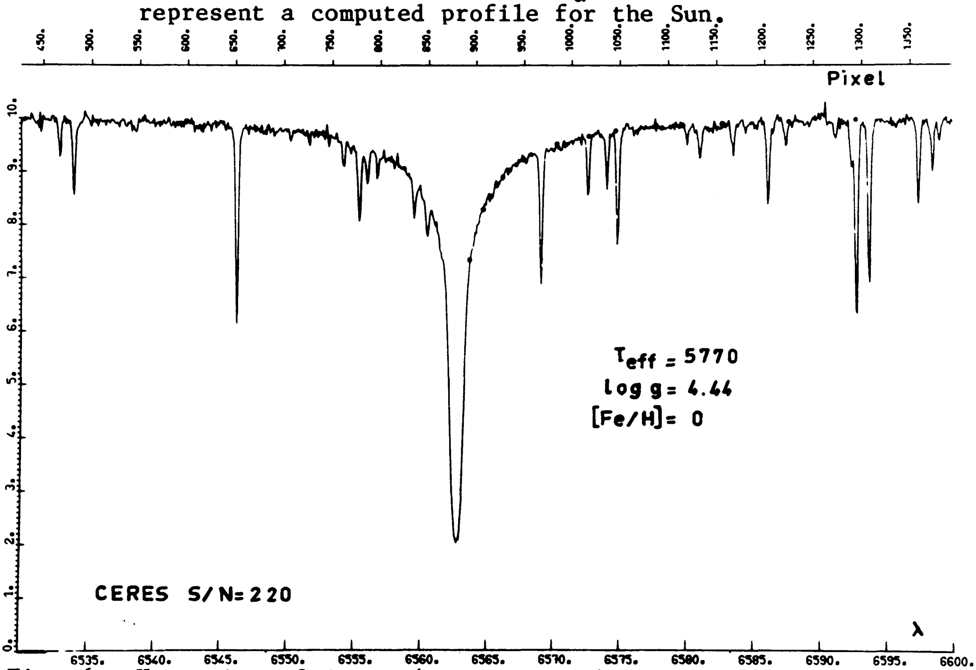

Fig. 6. H_α region of Ceres (V ≃ 8.0 mag.). Symbols as for Fig. 5.

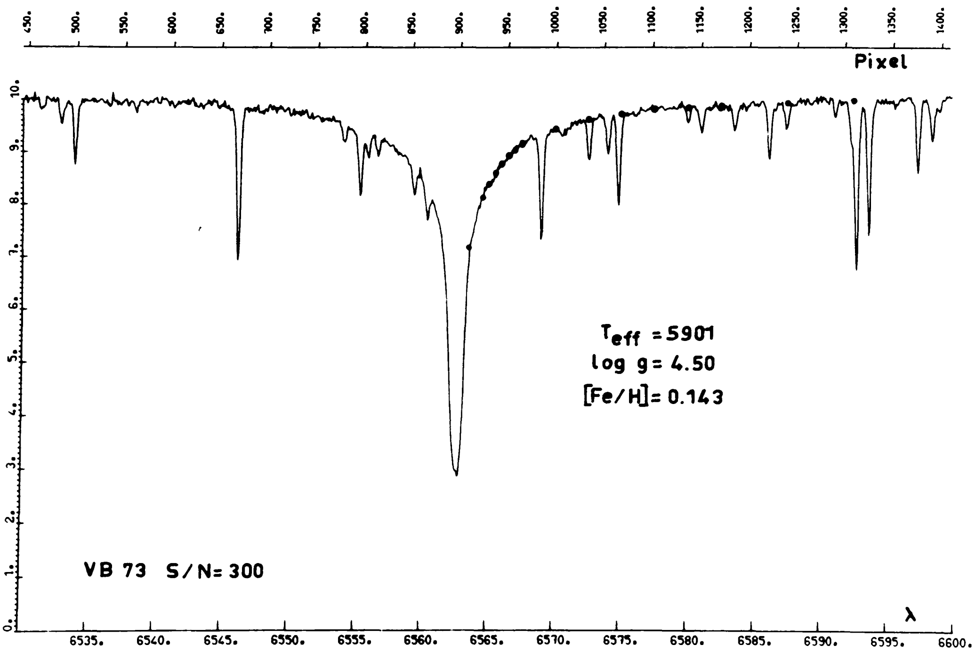

Fig. 7. CFHT Reticon spectrum of the H_α region of the Hyades dwarf VB73: dots represent a computed profile.

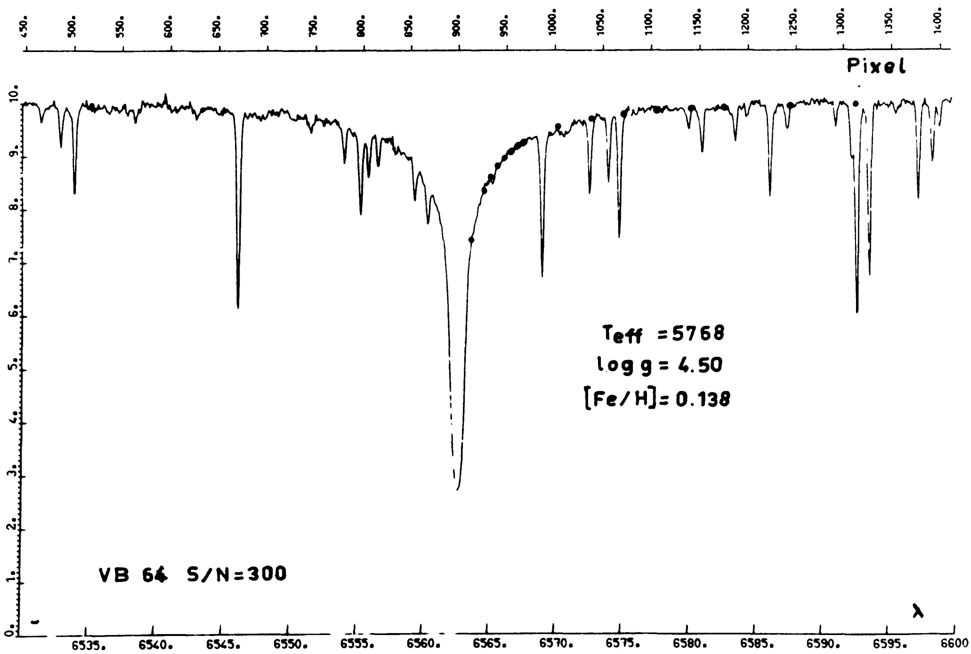

Fig. 8. H_α region for VB64. Symbols as for Fig. 7.

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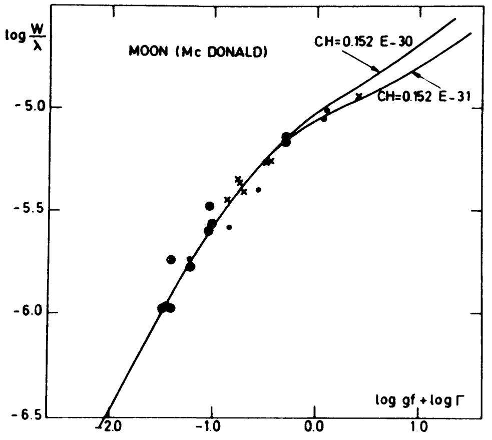

Fig. 9. Curve of growth constructed with Reticon equivalent widths of Sun (Moon) from Branch et al. (1980) Dots: H_α region lines, crosses: 6750 Å region lines, circled points: lines having solar oscillator strengths only. Solid lines are two theoretical curves of growth computed with two different damping constants, and with the atmospheric parameters contained in Table IV for the Sun (Ceres).

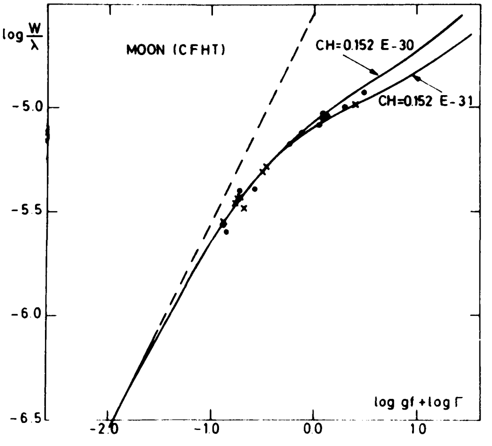

Fig. 10. Curve of growth constructed with Reticon CFHT equivalent widths of Sun (Moon). Here only lines having abso-lute oscillator strengths have been plotted. The abscissae are the same in Figs. 9 and 10. Note that the two observational curves of growth do not intersect the abscissa on the same point.

TABLE IV

[Fe/H] in 12 Hyades Dwarfs derived from about 35 Weak Iron Lines

Star	T_{eff}	θ_{eff}	log g	n number of lines	[Fe/H]	σ_1	σ_2
Ceres	5770	0.8735	4.44	45	+0.010	±0.069	±.035
VB73	5901	0.8541	4.50	43	+0.143	±0.066	±.035
VB97	5859	0.8602	4.50	36	+0.063	±0.081	±.035
VB52	5837	0.8635	4.50	41	+0.028	±0.066	±.035
HD1835	5774	0.8729	4.50	41	+0.165	±0.069	±.035
VB64	5768	0.8738	4.50	42	+0.138	±0.035	±.035
VB39	5622	0.8965	4.50	40	+0.028	±0.090	±.045
VB17	5568	0.9052	4.50	32	+0.095	±0.118	±.06
VB92	5540	0.9097	4.5	44	+0.137	±0.076	±.05
VB42	5398	0.9337	4.5	26	+0.101	±0.070	±.07
VB21	5293	0.9522	4.5	25	+0.093	±0.068	±.08
VB79	5235	0.9628	4.5	25	+0.136	±0.067	±.09
VB46	5169	0.9750	4.5	26	+0.070	±0.084	±.10

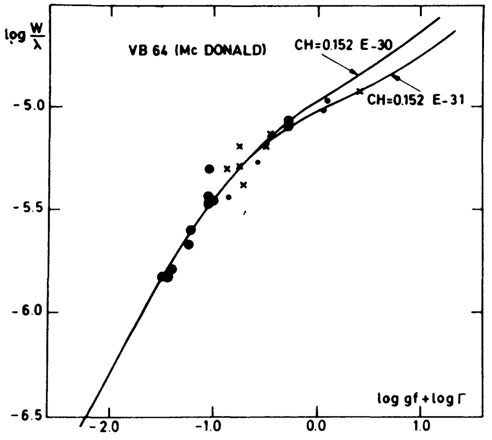

Fig. 11. Curve of growth constructed with Reticon equivalent widths of VB64 from Branch et al. (1980). Circled dots are lines with solar oscillator strengths.

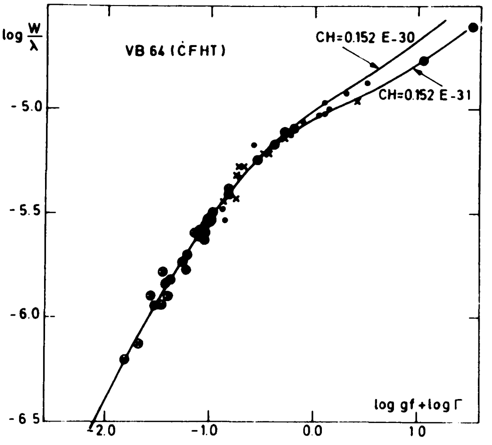

Fig. 12. Curve of growth constructed with CFHT equivalent widths of VB64. Same symbols as in the former Figs. Note the small dispersion of the observational curve of growth.

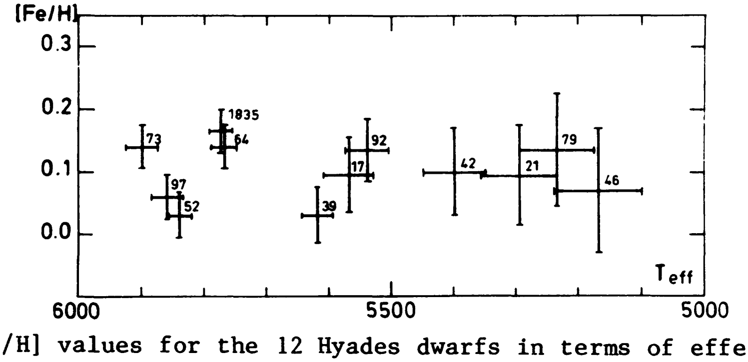

Fig. 13. [Fe/H] values for the 12 Hyades dwarfs in terms of effective temperature.

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This mistake has been made several times when the Sun was the comparison star, because of the existence of a large choice of specific models for the Sun. The point here is not to choose the "best" solar model but is to find [Element/H] = 0 when comparing a star identical to the Sun with the Sun. This implies that the solar model must be part of the grid used for representing the program stars.

We shall limit our estimate of the "modelling" error to the simple case in which one looks for the abundances of a dwarf G star relative to the Sun. In a dwarf the neutral lines are so insensitive to the exact value of the gravity that the lion's share of the error comes from the uncertainty in the temperature. This error can be determined from the H_α wing strength. A gain is realized here, too, with a high S/N ratio, which allows one to discriminate a smaller temperature change. In a solar type star a 100 K change produces a 10% change in the fractional depth of H_α at 4.0 Å from the center of the line, which is about four times what can be detected with a signal/noise ratio of 250. For lines with an ionization potential of 7 eV and an excitation potential of 3 to 4 eV, an error of 25 K produces an error in the Fe abundance of about 0.03 dex, which has to be compounded with the photometric error of 0.06 dex already quoted. Of course the random photometric error of 0.06 is smaller if several lines are available. Optimistically it is reduced by a factor of $\sqrt{n}$ if n good lines are available. This is the case for our spectroscopic material of the Hyades. For 7 out of 12 stars we have determined their [Fe/H] abundance and the other atmmosphere parameters T_{eff}, g, and ξ_t, with more than 40 good weak lines. For the faintest stars and for VB17 we choose about 25 good lines to determine the same parameters. Table IV gives the values of these parameters. Note that we have chosen the same microturbulence for all of the stars i.e., $\xi_t = 1.0$ km s^{-1}. The last two columns contain the standard deviation σ_1 with respect to the mean of [Fe/H] derived from one line only, and the estimated error σ_2 in the mean including effects of the error in temperature. From Table IV and Fig. 13, which represents the abundance versus T_{eff} relation for the program stars, we can see that the [Fe/H] value has a non-zero dispersion within the Hyades, the individual values ranging from 0.03 to 0.165 dex. This dispersion might be explained by spurious effects on the line strengths caused by the large chromospheric activity of these young stars.

In conclusion, an accuracy of 0.05 dex is now quite possible for abundances derived from spectra at a high signal/noise ratio. But yet, it should be remembered that this accuracy degrades if the objects compared do not have similar effective temperatures and gravities, the role of departures from LTE and other model weaknesses becoming more relevant. In particular, comparisons between a dwarf and a giant are probably dominated by such effects and not by the computable errors given in this paper.

A third source of error in an absolute abundance determination is the lack of reliable oscillator strengths for weak lines. We have therefore worked strictly differentially with respect to the Sun in carrying out the abundance determination of the Hyades dwarfs. But this is not always possible, especially for hot stars, and oscillator strengths can then become the cornerstone of abundance determinations.

4. THE [Fe/H] CATALOGUE

The aim of our Reticon observations of field stars and nearby open cluster stars of solar type and later is to obtain for these stars very reliable abundance determinations. The aim of the publication of the[Fe/H] Catalogue is to see which stars have been given a detailed anaylsis, possessing therefore detailed metal abundance determinations. The two aims are not at all the same. The Catalogue has been built up from very heterogeneous spectroscopic material: the [Fe/H] abundances contained in it come from many telescopes, many spectrographs, many detectors (chiefly photographic plates) and many authors, who in their analyses used all kinds of model atmospheres. The abundance analyses we have begun at CFHT and ESO are based upon excellent observing material and a homogeneous set of model atmospheres. The features that the "Reticon" and the "Catalogue" abundances have in common is that they are all "spectroscopic" abundances determined by coarse or detailed analyses based on reasonably well resolved spectrographic observations. The first list of metal abundance determinations was compiled by Cayrel and Cayrel de Strobel (1966). The authors took as the metal/hydrogen parameter the logarithmic difference between the relative abundance of iron in a star and the relative abundance of iron in a standard star. This difference is written in the form:

$$[\mathrm{Fe/H}]^{\mathrm{star}}_{\mathrm{std}} = \log\,(\mathrm{Fe/H})_{\mathrm{star}} - \log\,(\mathrm{Fe/H})_{\mathrm{std}}$$

In Table I of the paper by Cayrel and Cayrel de Strobel (1966) only five columns are given: column 1 contains the designation of the star, 2, its HD number, if any, 3, spectral type, 4, the value of [Fe/H], and 5, the bibliographic source. The number of stars contained in this table is 154.

It was Bernard Hauck, at the beginning of the seventies, who had the idea of publishing a "Metal Abundance" Catalogue. When the first Catalogue was compiled (Morel et al. 1976) it could have been called as well "A Stellar Atmospheric Parameters Catalogue" because together with distance and photometric parameters it contains other atmospheric parameters such as: effective temperature, gravity and microturbulence. Note that the chemical abundance, effective temperature, gravity and microturbulence are true physical parameters. On the other hand the photometric index (V-K) is an effective temperature indicator, but it does not give the effective temperature directly, the index needing to be calibrated. The [Fe/H] Catalogue could be very useful to astronomers interested in stellar atmospheres and stellar structure, but the values of the atmospheric parameters given in it for each star have to be reliable. How reliable they are, we do not know. The Catalogue is and has been very useful to photometrists interested in calibration problems. It has also been very useful in studies such as those on the fine-structure of the HR diagram for the solar neighborhood stars by Perrin et al. (1977) and on the status of evolution of F, G and K field stars by Cayrel de Strobel and Bentolila (1983). But as a matter of fact even if the Catalogue contains the true physical parameters of 1035 stars (see the 1984 edition), the values do not have the accuracy of the determinations presented in the first part of this talk. Since the first list of [Fe/H] determinations by Cayrel and Cayrel de Strobel (1966) the number of new stars being submitted to a detailed analysis is increasing continuously: this increase seems to be remarkably constant (about 100 new stars and 200 new analyses per year). Table V, taken from the 1984 edition of the Catalogue, presents the growth of data.

We thought that it would be useful to include two appendices in this abundance review. In Appendix 1 we list the individual values of effective temperature gravity and [Fe/H] for six spectroscopic standard stars. Appendix 2 gives a list of spectroscopic standards, compiled by the author and kindly revised by Mercedes Jaschek. These tables are self explanatory. However, I want to call the attention to the [Fe/H] abundance of α Lyr in Appendix 1.

Castelli and Faraggiana (1979) have analyzed the UV spectrum of α Lyr by means of IUE observations and found [Fe/H] = −1.36. This very low value of [Fe/H] from IUE spectra was confirmed although not quite so drastically by other authors. What has happened to give these results? It is not a suitable analysis? Is it an error in the reduction of the observations? Before we can understand this discrepancy I suggest not including this UV value in the mean. This is an example of how careful we have to be in using the [Fe/H] Catalogue, because α Lyr is not the only star for which we have found iron-abundance discrepancies between different authors.

TABLE V

GROWTH OF DATA OF THE [Fe/H] CATALOGUE

year of publication	Number of stars	Number of [Fe/H] determinations
1966	154	204
1976	515	973
1980	628	1109
1981	707	1298
1984	1035	1921

5. CONCLUSION

We have seen that the photometric accuracy of the equivalent widths measured on Reticon spectra has improved by almost an order of magnitude over those obtained by older conventional techniques. Under such conditions we have been able to measure lines really located on the linear part of the curve of growth, even in the case of stars of 8th to 9th apparent magnitude such as the Hyades dwarfs we have observed. Unfortunately very few of the weak 4-5 eV lines have measured oscillator strengths. This is not a handicap if we work strictly differentially with respect to the Sun, as for solar-type dwarfs. But for G and K giants and for O, B, A and M stars the absence of oscillator strengths can become a very great handicap in obtaining reliable abundances. We have seen that if a homogeneous grid of models is used both for representing the standard star and the analyzed star (such as that of Gustafsson 1978), the abundance, effective temperature, gravity and microturbulence of the star can be determined without bias. But for hot stars and cool giants the models one uses have to be computed with a non-LTE assumption if we want to improve the abundance results.

The tremendous breakthrough of high signal/noise, high resolution spectrographic observations has made possible the observing of faint stars which high dispersion spectroscopists never would have dreamed of observing even a few years ago. It is happily no longer true what Alan Batten said at the beginning of this conference: at present there are available more stars than Procyon and Arcturus observed at high resolution and high signal/noise ratio, suitable for accurate detailed spectroscopic analyses. Between Procyon and Arcturus and the Hyades dwarfs we have observed at the Canada-France-Hawaii Telescope, the flux ratio is about 3×10^3. I hope that the CCD and Reticon techniques will continually improve so the high dispersion spectroscopists can penetrate deeper and deeper into our Galaxy.

ACKNOWLEDGEMENTS

I cannot finish this talk without acknowledging that the abundance results of the 12 solar type Hyades could not have been realized without Bengt Gustafsson who provided us with very suitable models, Bruce Campbell who installed the Reticon at CFHT and worked with Roger Cayrel and myself on this project, and last but not least Gordon Walker who constructed the CHFT Reticon. Special thanks go to Claire Bentolila for her precious help in the preparation of the data for this paper. The paper has been revised by the editors of this Symposium. Sylvie Boucherie has typed the first version, and Pat Cochrane of KPNO has typed the final version. Many thanks to them also.

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APPENDIX 1

INDIVIDUAL VALUES OF [Fe/H] ABUNDANCES OF SPECTROSCOPIC STANDARD STARS CONTAINED IN THE [Fe/H] CATALOGUE

α LYR = HD 172 167; A0V

AUTHORS	T_{eff}	log g	$[Fe/H]^*_o$
HUNGER (1960)	-	-	-0.3
STROM and STROM (1966)	-	-	+0.05
STROM et al. (1966)	9000	3.8	+0.06
ALLER and ROSS (1967)	10080	3.5	+0.2
CONTI and STROM (1968)	9509	4.0	-0.1
PRZYBYLSKI (1968)	8692	-	-0.1
STROM et al. (1968)	9509	3.7	-0.1
GEHLICH (1969)	9164	4.0	-0.25
SMITH (1974)	9692	4.0	+0.02
BOYARCHUK and SNOW (1978)	9692	-	-0.9
BOYARCHUK and SNOW (1978)	9692	-	-0.5
CASTELLI and FARAGGIANA (1979)	9692	4.1	-1.36
DREILING and BELL (1980)	9692	3.9	0.0
SADAKANE and NISHIMURA (1981)	9692	3.94	-0.58

PROCYON = HD 61421; F5 IV-V

AUTHORS	T_{eff}	log g	$[Fe/H]^*_o$
GREENSTEIN (1948)	6222	-	+0.22
WRIGHT (1951)	6720	-	-0.40
EDMONDS (1965)	6450	4.0	-0.29
MERCHANT (1966)	6300	-	+0.03
POWELL (1970)	6630	-	+0.07
GRIFFIN (1971)	6540	-	0.00
HASEGAWA (1975)	6720	-	+0.74
TOMKIN and LAMBERT (1978)	6630	4.0	-0.15
KATO and SADAKANE (1982)	6630	4.0	+0.02

HD 219 134 K3 V

AUTHORS	T_{eff}	log g	$[Fe/H]^*_o$
CAYREL de STROBEL (1964)	4582	-	0.00
CAYREL de STROBEL (1966)	4710	4.50	+0.10
CAYREL de STROBEL et al. (1970)	4710	4.50	-0.01
STROMBACH (1970)	4710	4.50	0.00
OINAS (1974)	4667	4.40	-0.21
PERRIN et al. (1975)	4667	4.50	0.00
OINAS (1977)	4710	4.50	+0.20

ε VIR = HD 113226; G8 III

AUTHORS	T_{eff}	log g	$[Fe/H]^*_o$	REFERENCE STAR
GREENSTEIN and KEENAN (1958)	4421	-	+0.04	SUN
CAYREL and CAYREL (1963)	4941	2.7	+0.01	SUN
HELFER and WALLERSTEIN (1964)	5305	-	-0.15	γ, δ, ε TAU
CAYREL de STROBEL (1966)	4941	2.7	-0.03	SUN
HELFER and WALLERSTEIN (1968)	4421	2.45	-0.15	γ TAU
CAYREL de STROBEL et al (1970)	4941	2.70	-0.06	SUN
STROM et al. (1971)	4990	3.00	-0.1	SUN
VAN PARADIJS (1973)	4990	2.85	+0.04	SUN
BLANC VAZIAGA et al. (1973)	4941	2.70	+0.02	SUN
CAYREL et al. (1977)	4990	2.60	0.00	SUN
SNEDEN et al. (1978)	4990	2.75	-0.02	SUN
BRANCH et al. (1978)	4990	3.00	+0.17	SUN
HEARNSHAW and NEWBURGH (1979)	5040	2.70	-0.05	SUN
LAMBERT and RIES (1981)	5305	3.22	+0.21	SUN

μ LEO = HD 85503; SMR K GIANT

AUTHORS	T_{eff}	log g	$[Fe/H]^*_o$	REFERENCE STAR
STROM et al. (1971)	4755	2.7	+0.1	γ, δ, ε TAU, εVIR
BLANC-VAZIAGA et al. (1973)	4460	2.20	-0.08	εVIR
OINAS (1974)	4460	2.4	-0.01	SUN
PETERSON (1976)	4420	2.3	+0.03	SUN
PETERSON (1976)	4421	2.3	-0.11	SUN
BRANCH et al. (1978)	4541	2.35	+0.48	SUN
LAMBERT and RIES (1981)	4710	2.82	+0.11	SUN

HD 122 563; HALO K-GIANT

AUTHORS	T_{eff}	log g	$[Fe/H]^*_o$
WALLERSTEIN et al. (1963)	4065	-	-2.9
PAGEL et al. (1965)	4271	-	-2.65
BELL and PAGEL (1967)	4200	-	-2.6
WOLFFRAM (1972)	4582	1.2	-2.72
SNEDEN (1973)	4624	1.2	-2.7
SNEDEN (1974)	4582	1.2	-2.75
SPITE and SPITE (1978)	4582	0.9	-2.6
SPITE and SPITE (1979)	4582	0.9	-2.5
SPITE and SPITE (1980)	4582	0.9	-2.5
LUCK and BOND (1981)	4582	0.80	-2.59
BESSELL and NORRIS (1981)	4667	0.7	-2.7
STEENBOOK (1983)	4582	1.2	-2.61
LUCK and BOND (1983)	-	-	-2.35

APPENDIX 2

SOME STANDARD STARS FOR SPECTROSCOPIC ANALYSES

STAR	HD	V	B-V	Sp. Type	T_{eff}K	log g	$[Fe/H]^{*}_{o}$	Remarks
10 Lac	214680	4.88	-0.20	O9 V	37450	4.45		no Fe lines in the spectrum
τ Sco	149438	2.82	-0.25	B0 V	35000	4.35		
γ Cas	5394	2.47	-0.15	B0.5 IVe	-			"
ζ Per	24398	2.85	+0.12	B1 Ib	27000			"
γ Peg	886	2.83	-0.23	B2 IV	21910	3.7	+0.04	
105 Tau	32991	5.89	+0.19	B2 Ve	-	-	-	
55 Cyg	198478	4.84	+0.41	B3 Ie	14260			
134 Tau	38899	4.91	-0.07	B9. 5 V	11455	-	-	very narrow lines
α Lyr	172167	0.03	0.00	A0 V	9692	3.94	-0.06	
Hertzsprung II 2507	23964	6.74	+0.06	B9.5 Vp	-	-	-	Pleiades cluster star
β UMa	95418	2.37	-0.02	A1 V	10286	4.30	+0.78	UMa nucleus star
θ Vir	114330	4.38	-0.01	A1 V	9510	4.0	0.00	
63 Tau	27749	5.64	+0.30	A1 m	7640	4.4	+0.57	Hyades cluster star
29 Cyg	192640	4.97	+0.14	A2 V	8000	3.9	-0.80	
α Cyg	197345	1.25	+0.09	A2 Iae	9160	1.13	+1.00	
-	161817	6.97	+0.16	A2 V pec	7695	3.0	-1.30	Halo horiz. branch
15 Vul	189849	5.64	+0.30	A4 III	8000	3.5	0.00	
θ Cep	195725	4.22	+0.20	A7 III	7640	4.0	+0.13	
30 L Mi	90277	4.74	+0.25	F0 V	6720	-	+0.20	
	106516	6.11	+0.46	F6 V bvw	5930	4.3	-0.50	
α C Mi	61421	0.38	+0.42	F5 IV-V	6630	4.0	-0.15	
41 Cyg	195295	4.01	+0.40	F5 II	6720	2.50	-0.05	
γ Lep A	38393	3.60	+0.47	F8 IV	5660	-	-0.07	UMa stream star
π³ Ori	30652	3.19	+0.45	F6 V	6380	4.5	+0.10	
γ Ser	142860	3.85	+0.48	F7 V abw	6300	4.0	-0.24	old disk star
γ Pav	203608	4.22	+0.49	F6 V	6000	4.35	-0.62	old disk star
ο Aql	187691	5.11	+0.55	F8 V	6150	4.40	+0.12	
-	140283	7.20	+0.49	F9 V wl	5730	4.0	-2.15	Halo dwarf
Moon (Sun)	-	-	-	-	5770	4.43	0.00	chief standards for detailed
Ceres (Sun)	-	6.85	-	-	5770	4.43	0.00	analyses for F, G and K stars
	44594	6.60	+0.66	G3 V	-	-	-	Hardrop's solar twin
	81809	5.38	+0.64	G2 V	-	-	-	Mihala's solar twin
VB 73	28344	7.85	+0.60	G1 V	5900	4.50	+0.12	Hyades cluster star
VB 64	28099	8.12	+0.66	G2 V ?	5768	4.50	+0.15	" " "
VB 92	28805	8.66	+0.74	G8 V ?	5540	4.50	+0.16	" " "
	1835	6.39	+0.66	G2 V	5774	4.50	+0.19	Hyades group star
	10307	4.95	+0.62	G1.5 V	5860	4.38	-0.03	
α Cent A	128620	-0.01	+0.71	G2 V	5760	4.38	+0.26	$\pi = 0''.750$
	76151	6.00	+0.67	G3 V	5600	4.40	-0.02	The position in the HR diagram implies He-rich
85 Peg	224930	5.75	+0.67	G3 V	5200	4.35	-0.80	Old disk star
-	20630	4.83	+0.68	G5 V	5660	4.45	+0.08	
μ Cas	6582	5.17	+0.69	G5 Vp	5230	4.40	-0.70	Old disk star
31 Aql	182572	5.16	+0.77	G8 IV	5660	4.20	+0.40	Metal rich G-subgiant
Grmb 1830	103095	6.45	+0.75	G9 Vp	5040	4.60	-1.40	Halo dwarf star
ε Vir	113226	2.83	+0.94	G8 IIIab	4940	2.70	0.00	
β LMi	90537	4.21	+0.90	G9 IIIab	5090	3.00	+0.21	
36 Oph A	155886	4.31	+0.86	K0 V	5090	4.60	-0.01	
β Gem	62509	1.14	+1.00	K0 IIIb	4850	2.5	0.00	
γ Tau	27371	3.65	+0.99	K0 IIIab CN1	4990	2.6	+0.10	
α Cent B	128621	1.33	+0.88	K1 V	5250	4.73	+0.20	
-	190404	7.28	+0.82	K1 V	4990	4.50	-0.20	
36 Oph B	155885	4.33	+0.86	K1 V	5090	4.60	+0.09	
α Boo	124897	-0.04	+1.23	K1 IIb CN-1	4270	2.0	-0.50	Old disk giant
γ Lep B	38392	6.15	+0.94	K2 V	-	-	-	UMa stream star
μ Leo	85503	3.88	+1.22	K2 IIIb CN1 Cal Ba-1	4460	2.40	+0.07	Chief SMR candidate
-	122563	6.20	+0.90	K2 p	4500	1.00	-2.70	Halo giant
-	219134	5.56	+1.01	K3 V	4670	4.50	0.00	
36 Oph C	156026	6.34	+1.16	K5 V	4380	4.70	-0.06	
61 Cyg A	201091	5.21	+1.18	K5 V	4380	4.50	-0.07	
α Tau	29139	0.85	+1.54	K5 III	3920	1.20	-0.10	
61 Cyg B	201092	6.03	+1.37	K7 V	3880	4.60	-0.10	
β And	6860	2.06	+1.58	M0 IIIa	3250	-	+0.10	
	36395	7.97	+1.47	M1.5 V	3630	4.80	+0.60	
	204961	8.67	+1.46	M1 V	-	-	-	
	35601	7.35	+2.20	M1 Ib	4000	0.7	-0.24	

DISCUSSION

GRIFFIN, R. E. M.: In the pictures of reticon spectra which you showed, we could see some apparent emission spikes. Could you please explain their origin?

CAYREL: The spikes are caused by cosmic rays. They are even stronger in the Pleiades spectrum, but before the cosmic ray "events" become really disturbing you have gained at least three magnitudes in your your abundance work and I consider this a crucial advantage.

GRIFFIN, R. E. M.: If they are artifacts of the reticon and you cannot predict their positions, how can you be sure that they do not coincide with absorption lines? You say that you can measure confidently lines down to 2 mÅ, but how do you know there is not an artificial -6 mÅ line sitting on top of it? In my experience at the McDonald Observatory these spikes are observed in spectra of bright stars and they do not disappear by flat-fielding.

CAYREL: Yes, but though you may have spikes, you can observe much fainter stars with the Reticon.

GRIFFIN R. E. M.: It also appears that they are in the same place for several stars.

ARDEBERG: From your spectrograms I am quite sure that you have used the same background correction for all the spectrograms displayed. I think that you simply have to invest more time in your background measurements; then your spikes will diminish.

CAYREL: Yes. We did not use the same background corrections at CFHT. At CFHT four flat field exposures are taken after each stellar spectrum, having the same exposure level as the stellar spectrum. What I have shown is the ratio of the stellar exposure to the average of the four flat fields.

HEINTZE: For one observed H-alpha profile there are several combinations of effective temperature and log g that produce such a profile. How did you disentangle these two quantities?

CAYREL: We know that the surface gravity of the solar Hyades dwarfs is 4.5. They might be slightly more massive than the Sun. The microturbulent velocity is 1.0 km/sec. We got the effective temperature by comparison of observed H-alpha profiles with theoretical profiles. The corresponding uncertainty is less than 10°K.

GUSTAFSSON: You have obtained an impressive accuracy in the effective temperature determinations; however, it should be noted that these temperatures refer to the "effective temperature labels" of the models. For your abundance analysis the high accuracy in determining this label temperature is the relevant and important one, but one should warn

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people not to believe that your T_{eff}'s, as defined in the normal way related to the stellar surface flux, could be without systematic errors due to failures in the models of even more than 50°K.

CAYREL: We measured the depression in the line at 2.5 and 5.0 Å from the line center for the Hyades stars and the Sun. We calculated the ratio and compared with the grid of models. The Sun was compared with vB 64 or vB 73 and the temperatures agree extremely well between different spectra taken for the same star (typically ± 15°K).

GARRISON: One has to be as careful with Reticon spectra as we have learned to be with photographic spectra. Too many observers use the Reticon as a black box and believe everything that comes out, whether properly treated or not. Properly used, it is a beautiful tool, as you have said.

It will be nice to be able to use new detectors in the blue. With all the reports of spectroscopic binaries in the Hyades we cannot be sure that your H-alpha results translate to compare with blue results exactly for any particular star.

The signal-to-noise ratio quoted for photographic spectra does not tell the whole story in comparing with S/N for Reticons. At the MK workshop in Toronto (1983) this whole problem was brought up several times and it was agreed that Reticon spectra of S/N = 100 are not equivalent to photographic spectra. Millward's spectra of S/N = 1000 were much more comparable and even Morgan agreed that they could be classified using the MK process.

I wish people would not use the Moon as a source of solar spectrum. Unless the spectrograph is perfect, the use of an extended source will cause scattered light and will also fill the collimator differently. The result is that the H-lines look weaker; the metal lines also get filled in, making the spectrum look metal-weak. One thus concludes that the Sun is cooler and more metal-weak than it really is.

I wish people would not quote the compilations of spectral types, such as Jaschek, but rather use them as guides to get back to the original sources. Your types are Morgan's, not Jaschek's.

Finally, the case of vB 64 is an interesting one, with an interesting history. Hardorp has used it as evidence that the Sun is cooler than other stars classified G2 V. I took a good spectrum and found it to be close to that of the Sun, about G2 - G3, which is different from the type of G6 given by Morgan in his study of Hyades stars. After investigation, I found that he had classified his spectrum correctly, but that Hiltner had taken the wrong star! Thus his type of G6 V was not for vB 64 but for some other star. It is unfortunate that Hardorp concluded that the solar type was in error instead of trying to find out why the results were different.

CAYREL: Well, it is exciting to use a new technique. As to using the Jaschek catalogue, I trust it and do not have time to go back to the original sources. But the reader can always go to the Jaschek Catalogue and find the original sources. As for our use of the Moon, observations go much more quickly than with asteroids. We do have spectra of Ceres, and they agree very well with the Moon. As for vB 64, I will use G2 V for its spectral type.

ADELMAN: It is possible to obtain similar abundances from the Fe II lines in the optical and in the ultraviolet in B and A stars (Lekrone and Adelman, in preparation - Pi Cet and Nu Cap). One can increase the signal-to-noise ratio obtainable from photographic spectrograms by co-adding spectrograms. This is a useful technique when one needs a large spectral region provided one is working on bright stars. The process of co-addition should be checked by obtaining high signal to noise spectra of selected spectral regions with Reticons or CCD's.

The older elemental analysis of most B- and A-type stars suffers from systematic errors in the gf values of the atomic species used to determine the microturbulent velocity. This usually leads to errors in the microturbulence and in the elemental abundances. Whose Fe I gf values did you use?

CAYREL: May's. Blackwell has not yet measured 4 ev excitation Fe I lines (typically weak lines in our spectral range).

ADELMAN: The best Fe I gf values are those of Blackwell and his collaborators. Dr. J. R. Fuhr, National Bureau of Standards, has prepared a revision of the NBS critical compilation of gf values for Fe I lines. It will appear as part of a forthcoming volume on gf values of iron peak elements. Another useful source of Fe I gf values are the recalibration of Corliss and Bozman values by Cowley and Corliss (1983 MNRAS 203, 651). The recent gf values published in Astron. Astrophys. Suppl based on solar lines are also helpful (See, e.g., Gurtovenko, E. A. and Kostik, R. I. 1982, Astron. Astrophys. Suppl. 49, 193.). Some additional comments on gf values and atomic data are contained in my paper with C. R. Cowley (1983 QJRAS 24, 393). Let me note in closing that Dr. Fuhr and Dr. William C. Martin of the National Bureau of Standards have been most helpful to me and many other astronomers in giving advice on gf values, damping parameters, atomic energy levels, atomic line lists and other topics in atomic physics.

CAYREL: Thank you very much for your helpful comments. I have only one complaint about this symposium, happily, and that is that there are no papers on oscillator strengths. You have spoken for Dr. Blackwell, who is not here.

WALKER: Some of the Reticon spectra we have seen today have not been fully reduced. We have no difficulty achieving the high S/N per diode discussed and there is no problem with spikes in sea-level observations. CFHT spectra do have some cosmic ray events. For a critical discussion of the performance and calibration of our Reticon systems, see my paper in the Eighth Symposium on Photoelectronic Imaging Devices which is now in press.

GRIFFIN: I do not suppose that Madame Cayrel would expect me to subscribe to her remarks concerning the comparison between Reticon and photographic spectra! Without wishing to denigrate Reticons, I would like to suggest that the comparison is not so one-sided as it has been made to appear. Since much of my work is photoelectric, I feel that it is in order for me to say that a good deal of unwarranted prejudice has developed against photography in recent years. People seem to have been so carried away with Reticons, and we have got so used to seeing the words "high-resolution, low-noise" adhering to every reference to Reticon spectroscopy - often with the judicious use of initial capital letters! - that an impression almost of sacredness now surrounds everything to do with Reticons. The facts do not altogether merit that impression. For one thing, reticons are small. This smallness means that either the wavelength coverage is very short, or the binning of the spectrum is coarse, or both. Another comment I would make concerns signal/noise ratios. Few users of Reticons refrain from quoting signal/noise ratios (usually very high ones), presumably because they are very easy to calculate. They do not usually bother to tell us whether the quoted ratios are per bin, per resolution element or what. In any case, although the ratios are made to appear large, their significance seems relatively small. They are probably derived from inferred photon counts in the continuum and do not represent the true errors. There is an example of a Reticon spectrum in one of the poster papers: it shows absorption lines with equivalent widths of just a few milliangstroms and looks superficially to be a very nice tracing, but it does also show apparent emission lines with equivalent widths ranging up to about 6 mÅ. Such features are readily recognized as artifacts where they are seen on the continuum, but in a complicated spectrum some of them must inevitably compromise the profiles of absorption lines.

CAYREL: The occurrence of "spikes" is a very mild nuisance, because they are rare and do not reappear at the same location on several spectra. The basic advantage of a Reticon over the photographic plate is the much higher quantum efficiency of the solid state detector, which is conservatively at least 50 times the one of a good photographic plate. So, if the main interest is to reach fainter stars with a decent S/N ratio (such as globular cluster stars) one is compelled to use Reticon or photocounting devices, even if their wavelength coverage is smaller.