Metallicity and microturbulence in G and K giant stars.

By S. Andersen*, B. Gustafsson**, and P. Kjærgaard*

Abstract:

Observations of two photoelectric narrow-band indices measuring the strengths of two groups of faint and stronger metal lines respectively have been performed by means of an echelle spectrometer. The indices have been computed as a function of the fundamental stellar atmospheric parameters on the basis of model atmospheres. Using a new theoretical calibration of R−I as a measure of effective temperature, the comparison of observed and computed indices yields the following results:

1. The so-called microturbulence velocity is the same for nearly all stars; we find a mean value of 1.1 ± 0.2 km s$^{-1}$ for this parameter.

2. The logarithmic relative metal-to-hydrogen ratio with respect to the Hyades, [Fe/H], can be determined with an accuracy of about ±0.10 (m.e.).

3. The derived [Fe/H]'s are in good agreement with previous curve-of-growth determinations.

4. Stars with an iron-to-hydrogen ratio significantly greater than that of the Hyades seem to exist.

5. One of the metal rich stars found may be assigned an age of \( \approx 5 \times 10^8 \) years.

The observations have been carried out at l'Observatoire de Haute Provence, France, and Ole Rømer–Observatoriet, Århus, Denmark.

*Astronomisk Observatorium, Copenhagen

**Astronomiska Observatoriet, Uppsala
Introduction

The primary aim of this investigation is to provide a large homogeneous sample of relative metal-to-hydrogen ratios for the calibration of photometric classification systems. Furthermore we were especially interested in whether or not the so-called microturbulence velocity must be regarded as an independent parameter.

The problem of determining metal content and microturbulence velocity has usually been tackled by means of the curve-of-growth technique using photographic high dispersion spectrograms. However, a new method was recently introduced by Nissen (1970) who used photoelectric technique to observe a group of faint metal lines and analysed the observations by means of model atmospheres. Nissen's investigation of late F-type dwarfs was later extended to early F-type dwarfs by Gustafsson and Nissen (1972). In the present investigation we use the method introduced by Nissen.

Definition of the indices

Two narrow-band indices A(58) and A(48) were observed. Both indices measure the strength of a group of neutral metallic lines (mostly iron lines) relative to a nearby continuum region. The definition of an index is:

\[ A = \text{mag (line region)} - \text{mag (continuum region)} \]

The regions defining the A(58) index are shown in Fig. 1 together with the relevant part of the Solar spectrum taken from the Utrecht Atlas. Fig. 2 shows the regions defining the A(48) index together with the Solar spectrum. The A(48) index is almost identical with the A index used by Nissen (1970). The A(58) and A(48) indices were chosen to measure the metal content and microturbulence parameter respectively.
Fig. 1. The spectrum of the Sun near 5800 Å from the Utrecht Atlas and the transmission functions defining the A(58) index.

Fig. 2. The spectrum of the Sun near 4800 Å from the Utrecht Atlas and the transmission functions defining the A(48) index.
Instrumentation and observations

Both the echelle spectrometer and the observing procedure used by us were recently described by Gustafsson and Nissen (1972). Further details on the observing procedure will be given in a forthcoming paper (Andersen et al. (1973)). The spectrometer yields the transmission functions shown in Figs. 1–2. These functions have been measured photoelectrically using monochromatic light from a spectral lamp. The scattering in the spectrometer has been measured and taken into account.

The observations were made with the above mentioned spectrometer in connection with the 80 cm telescope of l'Observatoire de Haute Provence, France, and the 50 cm telescope of Ole Rømer-Observatory, Århus, Denmark. The A(58) index was observed twice for about 80 G and K giant stars, and for nearly 40 of these stars the A(48) index was also observed twice. The observation of a star consists simply in first correcting for the radial velocity of the star and then measuring the light alternately through the line and the continuum region exit slots. From repeated measurements of standard stars as well as program stars it was found that the mean error of an index based on two observations is ±0.004 mag. Fig. 3 shows the observed distribution of the stars in the A(58)–A(48) diagram.

The model atmospheres

When calibrating observations of the present type it is necessary to use model atmospheres. In this investigation we mainly use scaled Solar models, i.e., we scale the $T^{-1/5000}$ relation of the empirical Harvard Smithsonian Reference Atmosphere for the Sun (Gingerich et al. (1970)) to other effective temperatures. With the temperature dependence of depth given we integrate the pressure equation and calculate absorption coefficients. Here we have included continuous absorption contributions from H I, H$^{-}$, H$^{+}$, H$_{2}$, C I, Mg I, Al I and Si I and scattering from H I and electrons. The only important con-
tributions within the actual wavelength intervals come from H I, H and from scattering by H I.

When we use the empirical Solar model atmosphere, blanketing effects on the T- relation are considered in the zero'th approximation. However, differential blanketing effects, due to different metal abundances or microturbulence may be of importance. We have investigated this by using, as an alternative, a set of roughly blanketed models in radiative equilibrium constructed by Carbon (Strom et al. (1971)) who kindly furnished us with details. There are no important differences in the results of the analyses when using the different sets of models, at least not for stars with (R-I)<0.60. This is also true if we do the analysis with a set of unblanketed models including convection constructed by us. This illustrates the fairly small model dependence of the indices.

Theoretical calibration of the indices

Using the above mentioned model atmospheres the indices can be calculated as a function of effective temperature, gravity, metal content and microturbulence parameter (the velocity $\xi$ is assumed to be constant through the atmosphere). This computation is carried out as described by Nissen (1970). The calculation requires knowledge of the transmission functions already mentioned, as well as scattering in the spectrometer. Furthermore, the damping constant as well as the $gf$-values for the lines in question should be known.

The damping constant is fixed at 2.5 times the classical van der Waal's constant. We have deduced the value from the paper by Foy (1972); however, we should mention that changing the constant within reasonable limits (1-5 times the classical constant) produces at maximum only an effect in the calculated indices comparable to the observing errors. The $gf$-values for the lines are found by fitting computed Solar equivalent widths, using the Harvard Smithsonian Reference Atmosphere, to the observed ones from the McMath-Hulbert Atlas of the Solar Spectrum. Tracings of this Atlas have kindly been provided by Dr. O.C. Mohler.
It is necessary to estimate the effective temperatures and surface gravities of the stars. As a measure of the temperature \( R - I \) (in the Johnson system) was calculated, taking into account all the lines entering the R and I bands. This was done by Andersen (1972) who used a statistical method and the weighting function technique introduced by Gussmann (1967). The indices are not very gravity dependent; a rather rough determination of \( g \) is therefore sufficient. We have estimated \( g \) from \( M_V \) using a relation between \( T_{\text{eff}} \), \( M_V \) and \( g \) derived from Iben's (1967) evolutionary tracks.

![Graph showing the position of stars in the A(58) - A(48) diagram.](image)

Fig. 3. The position of stars in the A(58) - A(48) diagram. The separation of models with different \( \xi_t \) parameters has been indicated.
Results and discussion

From the observed $R-I$, $M_V$, $A(58)$ and $A(48)$ of a star we deduce $T_{\text{eff}}$, $g$, $[\text{Fe/H}]$ and $\xi_t$. The results concerning the microturbulence parameter are illustrated in Figs. 4 - 6.

![Figure 4](image1.png)

**Fig. 4.** The microturbulence parameter $\xi_t$ versus the effective temperature. The error bars show the maximal and minimal value of $\xi_t$ when $A(58)$ and $A(48)$ are varied within the mean errors of the observations.

As is seen, the microturbulence parameter is remarkably constant within the actual region of the $T_{\text{eff}}-g-[\text{Fe/H}]$-space. The variation observed may be wholly accounted for by the observational errors. The small spread in $\xi_t$ is the reason for the good correlation between the two indices shown in Fig. 3.

![Figure 5](image2.png)

**Fig. 5.** The microturbulence parameter versus the logarithmic gravity.

![Figure 6](image3.png)

**Fig. 6.** The microturbulence parameter versus the metal abundance relative to the Sun (determined under the assumption of $\xi_t$ equal to 1.1 $\text{km s}^{-1}$).

LIV-7

Provided by the NASA Astrophysics Data System
We feel that the constancy of $\xi_t$ could give some information about the physical nature of the phenomenon called microturbulence. Moreover it allows us to give the parameter $\xi_t$ a fixed value through the rest of the analysis. We obtained $\xi_t$ equal to $1.1 \pm 0.2$ km$^{-1}$. This value, however, is somewhat dependent on the zero-point constants of the photometry, which still have only preliminary values.

![Graph showing metal abundance comparison](image)

Fig. 7. Our determinations of metal abundance $[\text{Fe/H}]_{\text{AGK}}^H$, relative to the Hyades, compared with curve-of-growth determinations (○, Helfer and Wallerstein (1968)), and with determinations by means of narrow-band photometry (●, Hansen and Kjærgaard (1971)).

Fig. 7 shows that the metal abundances derived correlate fairly well with earlier curve-of-growth determinations and determinations by means of narrow-band photometry. However, since the abundances from the narrow-band photometry are calibrated on curve-of-growth determinations, the balls and dots in Fig. 7 should be well related to each other.

For the Sun we get a $[\text{Fe/H}]$ value close to $-0.40$ (relative to the four Hyades giants observed) with our preliminary values of the zero-point constants of the photometry. This value is in good agreement with the value recently obtained by Gustafsson and Nissen (1972).
The possible existence of super-metal-rich stars is, of course, of a certain interest. Fig. 7 indicates the existence of at least six stars (HD nos. 9927, 35295, 78479, 85593, 102328, 125560) with a metal content considerably in excess of that of the Hyades. All these stars have earlier been suggested by other investigators to be super-metal-rich. Special attention is here drawn to the star HD 35295 for which we deduce \([\text{Fe/H}] \approx +.3\). This star has a physical companion of spectral type F6 V, and observation of the secondary in the A(48) index likewise yields \([\text{Fe/H}] \approx +.3\). From four-colour photometry it is possible to derive the age \(\lesssim 5 \times 10^8\) years for the system.

One may ask whether one should rely upon any abundance determination of this kind when the physical nature of the microturbulence phenomenon is so unsettled. We have investigated the effect of a microturbulence parameter increasing with height. We find that a too small metal abundance is obtained when we perform the analysis, assuming a depth invariant microturbulence parameter. This indicates also, that if microturbulence were only a non-LTE effect our super-metal-rich stars would be still more metal rich.

**Conclusion**

We have found the present technique quite efficient and well suited for applications to studies of G and K type giants. The method is rapid and accurate; moreover it allows of a careful and fairly straightforward investigation of various systematical errors which might affect the results. The details of this investigation and of all results mentioned above will be published elsewhere (Andersen et al. (1973)).
References

Andersen, S. 1972, Thesis, Copenhagen University Observatory.

Andersen, S., Gustafsson, B., Kjærgaard, P. 1973, to be published.


Gingerich, O., Noyes, R.W., Kalkafen, W., Cuny, Y. 1971
Solar Phys. 18, 347.


DISCUSSION

Name : PAGEL

Question addressed to : KJAERGAARD

Have you got a definitive value for metal abundance of Hyades relative to the Sun, as previous Danish calibrations for F stars and for G-K giants were different?

Answer to PAGEL

F Stars (Nissen)  $^{+0.4}_{-0.3}$
G-K giant $^{+0.3}_{-0.2}$ perhaps

LIV-10

Provided by the NASA Astrophysics Data System