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Analyses of Crawford's *uvby*β calibrations using the pulsational variations of FG Vir

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Abstract

Crawford's *uvby*β calibration method is examined for A-type stars by comparing it with the pulsational variations of the observable m_1, c_1 and M_V for the δ Scuti star FG Vir. The fit between the calibration values of m_1 and M_V and the respective measurements for FG Vir are tested as a function of temperature based on 3068 4-colour values taken at the Observatorio de Sierra Nevada in Spain during the years 2002 and 2003. Testing is performed by means of linear regression. The fit between the measured index m_1 of FG Vir and the m_1 index of the Hyades is nearly perfect. A fit between the calibration value M_V and the measured values of FG Vir cannot be obtained with Crawford's calibration procedure in a straightforward manner. In order to achieve an optimal fit for M_V two modifications of the calibration procedure are investigated and discussed. (i) the position of the ZAMS given by Crawford is replaced by the position of the ZAMS given by Mermilliod; (ii) the influence of the mass difference on c_1 is taken into account.

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Individual Objects: FG Vir

1. Introduction

About five decades ago, Bengt Strömgren (1963, 1966) developed the *uvby* intermediate-band photometric system, which became a widely used tool for determining fundamental parameters of stars. First calibrations of the system were carried out by Strömgren and Crawford (1966, 1975, 1978, 1979) and by Perry, Olsen and Crawford (1987). So far, all studies were based on a large number of stars or sets of stars in order to improve the calibration of the parameters. Several investigations have been reported in the past on how the Strömgren parameters m_1 und c_1 behave during the pulsational variations of a single variable star. Rodríguez et al. (1991) investigated the behaviour of m_1 for several δ Scuti stars, Rodríguez et al. (1992, 1998, 2003) the behaviour of m_1 and c_1 for more δ Scuti stars, Stankov et al. (2002) the behaviour of m_1 and c_1 for the star SX Phe.

For the current investigation the δ Scuti star FG Vir has been used in order to test Crawford's *uvby*β calibrations. Various reasons make this star a suitable candidate, for instance:

a) FG Vir is a pulsating star and during its pulsation the star is varying in $T_{\rm eff}$, log g, etc., and the star's indices, at each moment, must resemble those of one standard star with the same parameters ($T_{\rm eff}$, log g, M_V and metallicity index m_1),

b) the data set used is very precise,

c) FG Vir is within the range of validity of Crawford's calibrations.

FG Vir is classified as an A5-type star on the Main Sequence (MS) with $< \delta c_1 > = 0.09$ mag as can be seen in Fig. 4; hence D(log g) is about 0.4 from ZAMS, and log g of FG Vir is 3.95. Last but not least, the star has nearly solar abundances: $< \delta m_1 > = 0.018$ as can be derived from Fig. 1; hence [Me/H] = -0.11 follows using Smalley's (1993) calibrations. According to this, one can assume FG Vir as an excellent candidate to test the ZAMS calibrations of Crawford (1979) or similar ones by Philip & Egret (1980).

Changes of luminosity according to the pulsational phase as well as of log g have to be taken into account for the determination of δc_1 relative to the ZAMS as will be outlined in section 7.. For High Amplitude δ Scuti (HADS) and SX Phe pulsators see for example the loops of $T_{\rm eff}$ and log g in the (c_1, $b-y$) diagrams during the pulsation cycle in Fig. 4 of Rodríguez et al. (1993), and Fig. 6 of Rodríguez et al. (2003) for V2109 Cyg. For the star SX Phe in Rolland et al. (1991) Fig. 8 shows an analogous behaviour.

Another question which has to be answered is that of the influence of metallicity [Me/H]. Let us assume a pulsating star similar to FG Vir as far as its location in the HR diagram is concerned but with a quite different metallicity, e.g. [Me/H] = - 3.0. Can we use this star to test Crawford's calibrations for the ZAMS? The answer is negative, because for this star the predictions for m_1 variations during the pulsation cycle, which imply the dependence on temperature, is very different from the predictions for the ZAMS. The prediction is valid for solar abundances. The predictions by the (m_1, β) grids change with $T_{\rm eff}$, log g and most important, with [Me/H] as Rodríguez et al. (1991) have shown in Fig. 3, i.e. m_1 of the star has to follow the predictions given by the corresponding (m_1, β) grids. And these predictions are quite different for a ZAMS star with solar abundances. Hence, the δm_1 index must vary during the pulsation cycle in agreement with the corresponding predictions. This does not mean that the metallicity of the pulsating star is varying. This means for this star that its m_1-index behaviour during the pulsation cycle is different from that predicted for a ZAMS star with solar abundances.

Even if we consider a pulsating High Amplitude star on the Main Sequence with solar abundances, we can find variations of δm_1 during the pulsation cycle. During the pulsation the surface gravity of the star is varying as well as its luminosity and the m_1-index behaviour depends on surface gravity too as shown by Rodríguez et al. (1991) (see, e.g., Fig. 2 and Fig. 4 of his paper). For high amplitude pulsations the dependence $m_1 = m_1(\mathit{log}\ \mathrm{g})$ must be taken into account to test the ZAMS calibrations.

To summarize: the metallicity index m_1 varies with effective temperature and to a less degree with surface gravity.

In the current investigation Strömgren photometric data for the δ Scuti star FG Vir were collected during 42 nights in the years 2002 and 2003 at the Observatorio de Sierra Nevada. For more details see section 2.

Out of these 42 nights 37 nights have been selected and were combined to an entity of 3068 records, with each record containing the measurements of u, v, b and y. These data can be regarded as data from different stars, since FG Vir is changing its surface temperature T_{eff}, its radius, its surface gravity g etc. during pulsation. On the contrary, the mass of FG Vir and the abundance of all elements remain constant.

Based on these measurements the present paper is testing the calibrations of the metallicity index m_1, the absolute magnitude M_V and the Balmer discontinuity index c_1 according to the tables and procedures given by Crawford (1979) for A-type stars. The observed values of the measured colours should fit the colours and M_V based on Crawford's calibrations. Linear relations between the physical properties of FG Vir are assumed because of its low amplitude pulsating behaviour.

The present paper demonstrates that a fit between the trends of the measured values of y with those of M_V, determined according to Crawford's calibration procedure, can only be achieved with essential modifications to the calibration procedure. Possible modifications of the calibration procedure are discussed.

2. Observations

The investigations in the present paper are based on measurements obtained with the 0.90 m telescope located at 2900 m above sea level in the South-East of Spain at the Observatorio de Sierra Nevada in Granada. The telescope was equipped with the simultaneous four-channel photometer (*uvby* Strömgren photoelectric photometer). For more details see Breger et al. (2004, 2005). In 2002 129 hours of data during 29 nights, and in 2003 24.9 hours during 8 nights were collected. This data set was selected for the final analyses because of its satisfactory small scatter. In total, this sums up to about 154 hours of observation time for both years.

In this paper it is implicitly assumed that the intrinsic values m_0 and c_0 of FG Vir are the same as the observed m_1 and c_1 ones. It is valid in the case of FG Vir because the reddening $\mathrm{E}(b-y)=0$ (see e.g. the reddening assuming the mean indices published in the catalogue of Rodríguez et al. (2000) for δ Scuti-type stars).

Moreover, the given data represent measurements in the *uvby* filters. I determined the β values directly from the corresponding $(b-y)$ ones assuming the $\beta(b-y)$ relation from Crawford (1979) for standard A-type stars. This is valid when, as in the case of FG Vir (more or less),

a) the reddening is null and

b) the star is on the Main Sequence.

If a star is not exactly on the Main Sequence, then a correction for "luminosity" has to be taken into acccount. See the relation in Crawford (1979) when δm_1 is positive:

$$(b-y)_0 = 2.946 - \beta - 0.1\delta c_1$$

In the case of FG Vir $\delta c_1 = 0.09$; hence a difference of about -0.009 mag occurs to the corresponding β values in the ZAMS which can be neglected with respect to the aims of my investigations, dealing with the testing of the trend of m_1 and M_V. Throughout this paper Crawford's (1979) transformation for the standard stars will be used for determining the corresponding β values for each data record, which will be used for all the following analyses.

3. Testing the temperature dependence of m_1 and δm_1

Crawford (1979) published calibrations of the Strömgren parameters for A-type stars based on measurements of a large number of different stars. The pulsating star FG Vir changes its luminosity, surface temperature and log g during a pulsation cycle. The mass, however, remains constant and the chemical abundance does not change either. Those are the prerequisites of this paper for checking the applicability of Crawford's (1979) calibration procedure through the change of the Strömgren parameter m_1 of the pulsating star FG Vir. In a first step the colour index $m_1(\beta)$ of FG Vir is compared to the colour index $m_1(\beta)$ of the standard stars (Hyades) as published by Crawford (1979).

The method of testing the agreement of the colour indices is a linear fit of $m_1(\beta)$ from which the slope k_m can be determined by:

$$m_1(\beta) = \mathrm{a_m} + \mathrm{k}_m\beta \ .$$

For better comparability of the two trends and taking into consideration the range of β for FG Vir, the $m_1(\beta)$ values of the standard stars have also been linearized.

Fig. 1 shows the good agreement between the trends of m_1 for the Hyades and FG Vir caused by the pulsations. Let us denote for each β $m_{1\mathrm{m}}$ as the "measured" values of FG Vir and $m_{1\mathrm{S}}$ as the values for the corresponding standard star. Crawford (1975) defined the blanketing parameter $\delta m_1(\beta) = m_{1\mathrm{S}}(\beta)$ - $m_{1\mathrm{m}}(\beta)$. This parameter can be used for a consistency test. The constance of δm_1 over the pulsation cycle (Fig. 2) supports the conformity of the trend of $m_{1\mathrm{m}}(\beta)$ and the trend of $m_{1\mathrm{S}}(\beta)$. The conformity of both trends is also shown in Table 1. Data have been divided into 5 contiguous groups each comprising about 610 records.

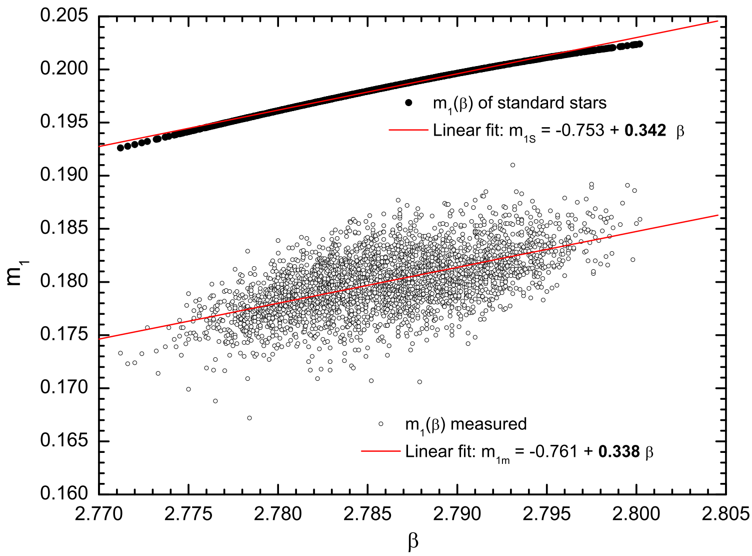

Figure 1: Comparison of the trend of m_1 of the standard stars with the trend of m_1 seen during pulsation of FG Vir. The shift between the two trend lines is caused by a different abundance between the Hyades and FG Vir. This has no effect to the calibration.

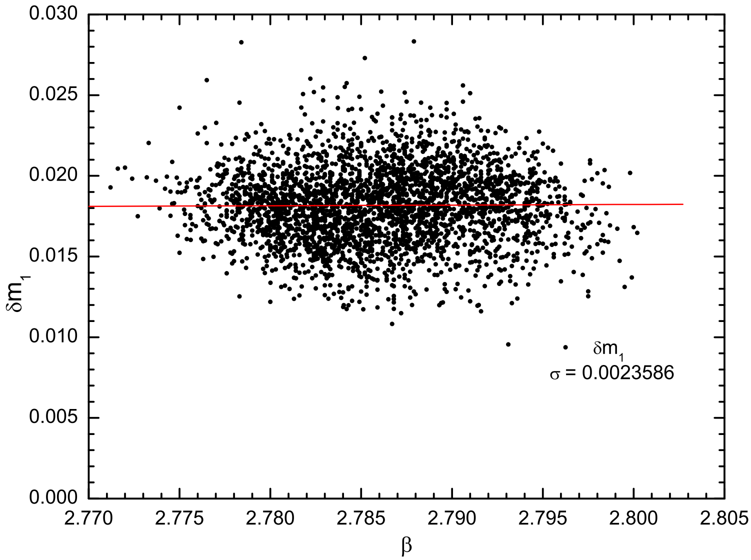

Figure 2: Consistency test based on δm_1

Table 1: Consistency test based on mean values of δm_1

$[\beta]$	$[b-y]$	$[\delta m_1]$	σ
2.779	0.167	0.0182	0.0020
2.783	0.163	0.0179	0.0025
2.786	0.160	0.0180	0.0025
2.789	0.157	0.0186	0.0025
2.793	0.153	0.0181	0.0022

If the size of the measured data sample is sufficiently large, a statement can be made with respect to the behaviour of the photometric index m_1 for δ Scuti stars pulsating with low amplitudes.

Evidently, the conformity of the trend of measured m_1 and the trend of calibrated m_1 depends on the abundances of the metals of the analysed star. Rodríguez et al. (1991) showed that differences in the behaviour of the m_1 variations in some stars with similar surface temperatures and gravities could be caused by different metallicities. Furthermore, Rodríguez (1991) pointed out that some authors assume a varying microturbulence velocity during a pulsation cycle responsible for the changing behaviour of m_1. This affects the strength of the metal-lines. Stankov (2002) showed that for the metal-poor star SX Phe no conformity of the trend of m_1 with the trend of the standard stars can be seen. Rodríguez (1991) explained this phenomenon with the existence of a different trend of m_1 for stars with low metallicities, referring to SX Phe stars explicitly, as a function of the δm_1-index variation and consequently also of the m_1-index variation. Over the pulsation cycle the variation of m_1 increases with decreasing metallicity. Önehag et al. (2009) investigated the calibration of Strömgren *uvby* Hβ photometry for G and F stars and tested the influence of temperature, gravity and metallicity on the m_1 index. The authors reported similar results as those found in this work on A-type stars.

4. Testing the temperature dependence of $c_1(\beta)$

The Balmer discontinuity-index c_1 provides an estimate for the luminosity of a star from the computed difference δc_1 relatively to stars at the ZAMS. For High Amplitude δ Scuti stars studies of the variations of the colour indices c_1 and δc_1 have been performed by Rodríguez et al. (1993 and 2003) and for SX Phe by Rolland et al. (1991). Also a study of the trend of δc_1 can be found in Stankov et al. (2002) for SX Phe. In their paper a value of $\delta V/\delta c_1 = 9.8$ for SX Phe is derived which is in good agreement with the value given in Crawford's (1975) paper for F-type stars.

For FG Vir the procedure, as specified by Stankov (2002), provides a value for $\delta y/\delta c_1 = 10.3$ as can be seen in Fig. 3. Note that by definition y = V. In this plot the band of y is segmented into 9 groups of equidistant width.

The above discussions relate to the behaviour of the Strömgren-index c_1 for the single star FG Vir. The paper of Crawford (1979) describes the calibration of c_1 at constant effective temperature $T_{\rm eff}$ and his results are based on the analysis of different stars with different masses. The dependence of the luminosity on the stellar mass will be shown in the following sections about the M_V calibration. The differences in mass have an influence (even if it is low) on the value of log g and consequently also on c_1.

5. Relation between δc_1 and δm_1 in A-type stars

Crawford (1979) examined the correlation between the trends of δc_1 and δm_1 for A-type stars and found a small relationship between these two indices: "... any star with a large δc_1 has a larger-than-average δm_1. Also, those stars with" more "negative δm_1 (the Am-type stars) have smaller-than-avergage δc_1. The

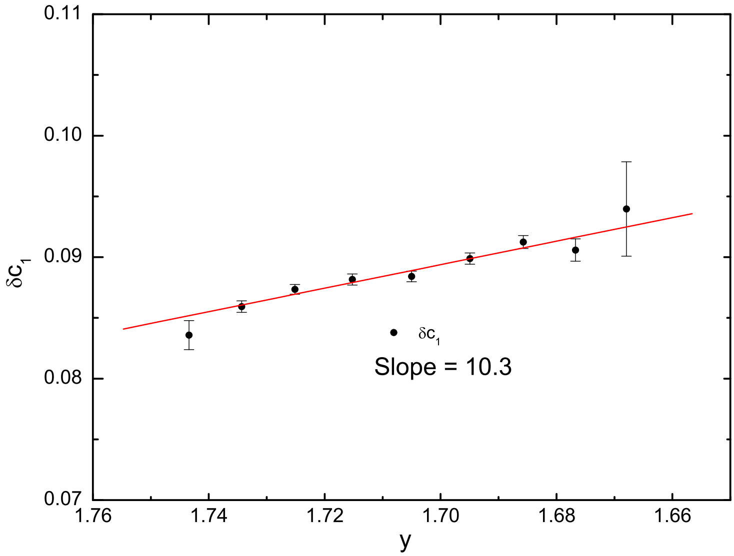

Figure 3: δc_1 versus y divided into 9 groups. This shows the agreement with the expected value of a slope of 9.0 for A-type stars derived for different stars by Crawford. The agreement can be improved by taking the mass effect into account.

values of both indices for FG Vir are located in a very "normal range. In Fig. 5 of Crawford's paper a trend can be found. Fig. 4 shows the relation of δc_1 and δm_1 for FG Vir. A linear fit to the FG Vir data in Fig. 4 lies completely within the cloud of points shown by Crawford (1979) in Fig. 5 of his paper. There is a clear trend in the sense of larger δc_1 values as the δm_1 values are also larger. This is the same trend as in the Crawford paper, but it is evident that the interpretation must be quite different (if existing) for a pulsating star. What does this trend mean in the case of FG Vir? If we inspect Fig. 2, $\delta m_1 = \delta m_1(\beta)$, we can either assume whether the "central" cloud of points (centred at $\beta = 2.785$ mag) is "only" due to "dispersal" of the data points or whether it is related to the pulsation phase of the star. And there are some more questions addressing the relation between the investigated properties and the phase. Questions with this respect are not subject of the current paper. FG Vir is a multiperiodic star and thus makes investigations very complex.

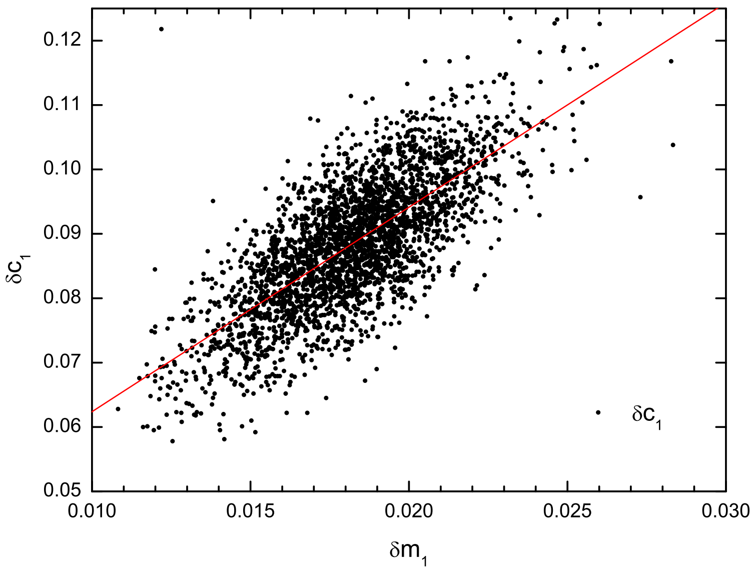

Figure 4: Relation between δc_1 and δm_1 for the measured values

6. Testing the temperature dependence of $M_V(\beta)$

In this section the trend between the colour measurements $y(\beta)$ of FG Vir and the calculated values for the absolute magnitude $M_V(\beta)$ according to Crawford's (1979) calibration are compared. This calibration determines $M_V(\beta)$ by means of $M_V(\text{ZAMS}, \beta)$ denoting the stars at the position of the ZAMS and $\delta c_1(\beta)$ according to:

$$M_V(\beta) = M_V(\text{ZAMS}, \beta) - f.\delta c_1(\beta) .$$

$M_V(\text{ZAMS}, \beta)$ and $c_1(\text{ZAMS}, \beta)$ are taken from Table I in Crawford's (1979) paper. Crawford proposes $f = 9$ for A-type stars and

$$\delta c_1(\beta) = c_1(\beta) - c_1(\text{ZAMS}, \beta) .$$

Hypothesis: the trend of $M_V(\beta)$, determined by Crawford's (1979) calibration as outlined above, confirms the trend of the measurements of $y(\beta)$ for FG Vir, i.e., M_V fits the measurements of $y = V$.

To verify this hypothesis the calculated values of M_V are fitted linearly to obtain the trend for $M_V(\beta)$, which is then compared to the trend of the measurements of $y(\beta)$ for FG Vir (also based on a linear fit).

Result: the initially postulated hypothesis for the trend of $M_V(\beta)$ cannot be confirmed under the strict application of Crawford's (1979, 1987) calibration procedure and Crawford's data for the position of the ZAMS. The fit between $M_V(\beta)$ and $y(\beta)$ of FG Vir is unsatisfactory.

The poor agreement between both trends can be seen immediately in Fig. 5.

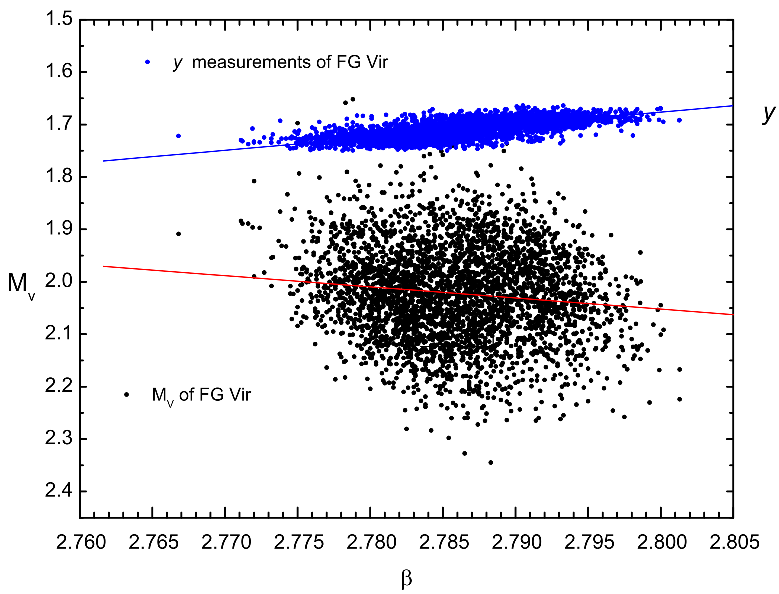

Figure 5: Comparison of the trend line of $M_V(\beta)$ according to Crawford's calibration and the measured values of y(β).

I examined which changes to the calibration procedure are necessary to improve the agreement between the trends of $M_V(\beta)$ and $y(\beta)$. The first step was to modify the factor f. Although a reduction of this factor improves the agreement between both fits, an optimal value for f could not be found.

The next question was whether a change to the adopted position of the ZAMS provides a better fit and how we can determine the "real" position of the ZAMS.

Mermilliod (1981) published a table for M_V(ZAMS, $B-V$) for the position of the ZAMS in the Johnson *UBV* system and added the remark: "…The present material may be used to redetermine the ZAMS." The table shows a different temperature dependency for M_V(ZAMS) compared to the one published by Crawford (1979). A transformation as indicated by Caldwell (1993) allows the representation of the table M_V(ZAMS, $B-V$) in a form suitable for the Strömgren *uvby*β photometric system. The substitution of Crawford's position of the ZAMS by Mermilliod's position of the ZAMS proved to be very effective for improving the agreement of the trends between $M_V(\beta)$ and $y(\beta)$. For the calibration of the Strömgren parameters Crawford (1979) selected the open clusters α Per, the Pleiades, IC 4665, the Hyades and data from the Coma cluster, UMa and Praesepe. In order to determine the position of the ZAMS, Mermilliod (1981) selected the open clusters α Per, the Pleiades, IC 4665 and additional open clusters younger than the Hyades.

With this modification to the position of the ZAMS the agreement between both fits improves substantially, but is still not perfect.

Fig. 6 illustrates the disagreement between both positions of the ZAMS definitions in the temperature region of FG Vir.

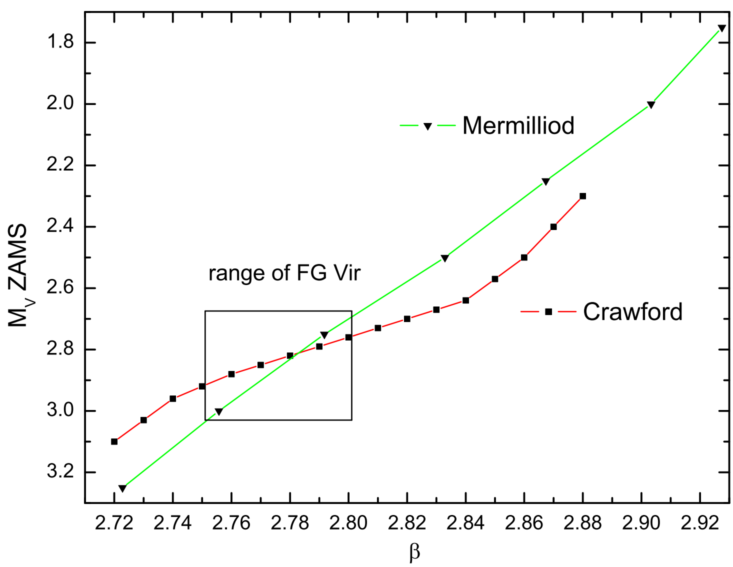

Figure 6: Comparison between the position of the ZAMS of Crawford and the position of the ZAMS of Mermilliod. The rectangle marks the temperature region of FG Vir.

We find that Mermilliod's values for the M_V values of the position of the ZAMS, M_V(Mer, β), and a reduction of the factor f in the calibration formula provides a better fit for M_V of FG Vir. This allows us to draw the following conclusion:

The optimal calibration leading to the best agreement between the trend of the measured values $y(\beta)$ and the trend of the calibrated $M_V(\beta)$ for FG Vir is obtained by the following equation (see Fig. 7):

$$M_V = M_V(\text{Mer}, \beta) - 7.1\delta c_1 \ .$$

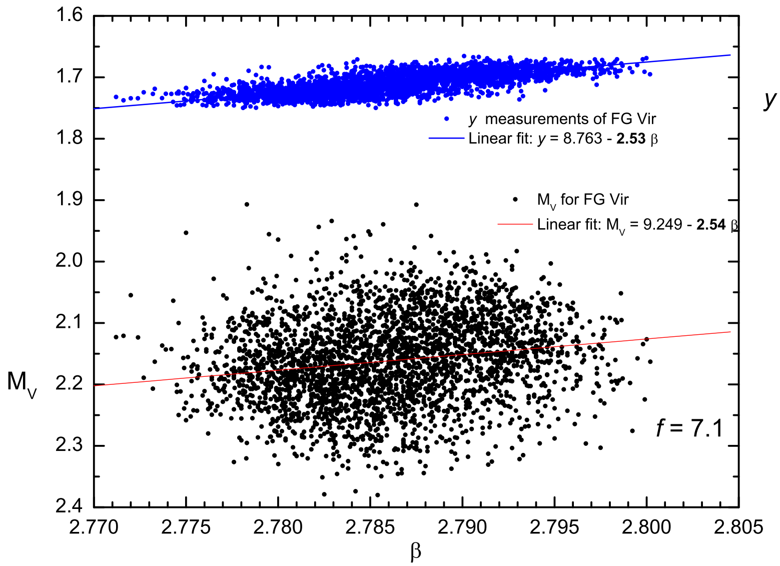

Figure 7: Comparison of the trend line for the measured values of $y(\beta)$ and trend line of $M_V(\beta)$ calibrated with M_V(ZAMS, β) as indicated by Mermilliod and the factor f reduced to $f = 7.1$.

These results, however, are still tentative since the effect of the mass has still to be taken into account (see section 7.). Hence, the next step will be to consider the effect of different masses. Are the different values for the factor f in Crawford's (1979) calibration and in the optimal calibration obtained in this paper a result of mass differences?

7. Effect of mass on the fundamental parameters of a main sequence star

In this paragraph the effect of the mass difference between FG Vir and main sequence stars with the same luminosity and temperature on log g and c_1 will be investigated.

Stars located on the main sequence are in similar stages of their evolution and therefore exhibit a similar internal structure. Therefore, a mass, $\mathcal{M}$, is in accordance with a specific absolute bolometric magnitude $M_{\rm bol}$ and hence a corresponding luminosity L. In Crawford's (1979) calibration procedure this relationship was kept in mind for A-type stars implicitly for the absolute magnitude M_V (and with it the determination of L and $M_{\rm bol}$). The analysis of my paper is focused on the application of the calibration relation of Strömgren photometry to determine the luminosity L of the single star FG Vir, which does not change its mass $\mathcal{M}$. During the pulsation cycle of the star mainly the variations of the fundamental parameters $T_{\rm eff}$ (included in $b-y$ and β), log g (included in c_1), L (included in y or in M_V, determined according to the calibration of Crawford) as well as the radius R are analysed. The mass $\mathcal{M}$ of FG Vir will remain unchanged during the pulsational variations and hence causes a different constellation in comparison with a normal main sequence star (this can also be seen as a perturbation of the equilibrium of the star). One can also make a prediction which mass $\mathcal{M}$ is consistent with the respective luminosity L for every pulsation phase and hence find out the difference of the mass of FG Vir compared to a "nominal value" (or position of an equilibrium model star). In other words, which should be the mass of the star FG Vir in every phase of the pulsation cycle in comparison with an unperturbed star?

I made quantitative estimates of the mass differences and their effect especially on the values of log g based on the same models and software as used by Lenz et al. (2008). Metallicity and rotational velocity of the stars are selected in accordance with FG Vir. The evolutionary tracks in Fig. 8 for different masses allow an estimate of the difference between the mass of FG Vir and the "nominal mass" of a corresponding unperturbed main sequence star. During each pulsation phase log L of FG Vir has to be identical to log L of a corresponding main sequence star. Furthermore, by definition the surface temperature $T_{\rm eff}$ is also the same for both stars. Taking into account the above constraints based on the relations between the fundamental parameters of a star, the following relation between surface gravity g and mass $\mathcal{M}$ can be derived:

$$g_{\rm FG}/g_{\rm MS} = \mathcal{M}_{\rm FG}/\mathcal{M}_{\rm MS} \ ,$$

where the subscript FG denotes FG Vir and MS a corresponding main sequence star. The deviation $(g_{\rm FG} - g_{\rm MS})$ caused by the mass difference between

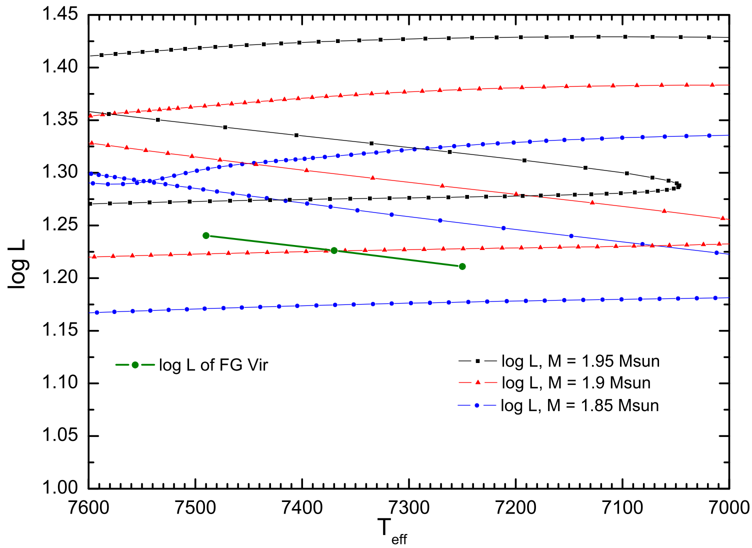

Figure 8: Comparison of evolutionary tracks for 3 main sequence stars with 3 different masses and a corresponding curve spanned by FG Vir with more than 75 frequencies ($\log L = \log L/L_\odot$).

FG Vir and a main sequence star with identical luminosity and temperature has an equivalent δc_1 value of ($c_{1FG} - c_{1MS}$). By means of the $c_1(\beta)$ diagram the corresponding c_1 values of the respective main sequence star can be determined. Metallicity and microturbulence of the stars in the diagram are selected in accordance with FG Vir. A description of the used atmosphere model grids can be found in Nendwich et al. (2004) and Heiter et al. (2002). Table 2 highlights 3 points of the temperature range (mean, maximum and minimum) caused by the pulsational variation range of FG Vir comparing the measured value of c_{1FG} to the respective "nominal value" c_{1MS} of the corresponding main sequence star. By definition the deviation of the mean value is chosen to be 0.0.

In the range of the temperature variation of FG Vir the maximal deviation of the nominal value c_{1MS} of the corresponding main sequence star is less than 5.5 % . One can substitute FG Vir's c_{1FG} by c_{1MS} of the corresponding main sequence star and compare the trends of the measured y values and M_V calculated according to Crawford's procedure, for FG Vir with the ZAMS

Table 2: Selected points of the deviation for c_1 between FG Vir and a main sequence star

$T_{\rm eff}$	β	$c_{1\rm FG}$	$c_{1\rm MS}$	$c_{1\rm FG}$ - $c_{1\rm MS}$
7490	2.800	0.860232	0.861322	0.00109
7370	2.786	0.840347	0.840347	0.00000
7250	2.771	0.819042	0.817962	-0.00108

of Mermilliod in place of Crawford's ZAMS. This leads to a good agreement between both trends.

A linear function can be derived from Table 2 for the determination of $c_{1\rm MS}$ as soon as the "measured" $c_{1\rm FG}$ value is known.

8. Conclusions

The current work presents an analysis of the behaviour of the two Strömgren indices c_1 and m_1 based on 3068 records of *uvby* Strömgren photometric data for the δ Scuti star FG Vir. Furthermore, the applicability of Crawford's (1979) calibration procedure for the determination of the trend of the absolute magnitude M_V during pulsations is critically tested by comparing the M_V calibration of FG Vir with the corresponding observed values.

The testing of the trend of m_1 of FG Vir confirms that the metallicity is not varying during the pulsation cycle. It fits with the trend of the standard stars. This can be seen by the fact that the blanketing parameter δm_1, which characterizes the metal content of the star, remains constant. Additionally to previous results for High Amplitude δ Scuti stars (Rodríguez et al. 1991), the confirmation is possible with the given data even for a δ Scuti star with low amplitude.

The testing of the trend of the absolute magnitude M_V, determined according to Crawford's (1979) calibration procedure, shows a poor agreement with the trend of the measured intrinsic colour y. The published calibration of M_V does not fit the measured values of FG Vir. I outline an approach to reach a satisfactory agreement by taking into account the effect of different masses on the trends of log g and c_1, especially by substituting the position of the ZAMS as outlined by Crawford (1979) with the position of the ZAMS as defined by Mermilliod (1981). Mermilliod indicates that a redefinition of the position of the ZAMS will be necessary based on his observations. The current work fully supports this statement.

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References

Breger, M., Rodler, F., Pretorius, M. L., et al. 2004, A&A, 419, 695

Breger, M., Lenz, P., Antoci, V., et al. 2005, A&A, 435, 955

Caldwell, J. A. R., Cousins, A. W. J., Ahlers, C. C., et al. 1993, SAAO, 15, 1

Crawford, D. L. 1966, IAUS, 24, 170

Crawford, D. L. 1975, AJ, 80, 955

Crawford, D. L. 1978, AJ, 83, 48

Crawford, D. L. 1979, AJ, 84, 1858

Heiter, U., Kupka, F., van 't Ver-Mennert, C., et al. 2002, A&A, 392, 619

Lenz, P., Pamyatnykh, A. A., Breger, M., & Antoci, V. 2008, A&A, 478, 855

Lester, J. B., Gray, R. O., & Kurucz, R. L. 1986, ApJS, 61, 509

Mermilliod, J. C. 1981, A&A, 97, 235

Moon, T. T., & Dworetsky, M. M. 1985, MNRAS, 217, 305

Nendwich, J., Heiter, U., Kupka, F., et al. 2004, CoAst, 144, 43

Nissen, P. E., Twarog, B. A., & Crawford, D. L. 1987, AJ, 93, 634

Önehag, A., Gustafsson, B., Eriksson, K., & Edvardsson, B. 2009, A&A, 498, 527

Perry, C. L., Olsen, E. H., & Crawford, D. L. 1987, PASP, 99, 1184

Philip A.G.D., & Egret, D. 1980, A&AS 40, 199

Rodríguez, E., Rolland, A., López de Coca, P., & Garrido, R. 1991, A&A, 247, 77

Rodríguez, E., Rolland, A., López de Coca, P., et al. 1992, A&AS, 96, 429

Rodríguez, E., Rolland, A., & López de Coca, P. 1993, A&AS, 101, 421

Rodríguez, E., Rolland, A., Garrido, R., et al. 1998, A&A, 331, 171

Rodríguez, E., López-González, M. J., P., & López de Coca, P. 2000, A&AS, 144, 469

Rodríguez, E., Arellano Ferro, A., Costa, V., et al. 2003, A&A, 407, 1059

Rolland, A., Rodríguez, E., López de Coca, P., et. al. 1991, A&AS, 91, 347

Smalley, B., & Dworetsky, M. M. 1993, A&A, 271, 515

Smalley, B. 1993, A&A, 273, 391
Stankov, A., Sinachopoulos, D. A., Elst, E., & Breger, M. 2002, CoAst, 141, 72
Strömgren, B. 1963, QJRAS, 4, 8
Strömgren, B. 1966, ARA&A, 4, 433