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Geneva photometry in the young open cluster NGC 6231*

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Abstract. We present photoelectric (127 stars) and CCD (168 stars) Geneva photometry for the very young open cluster NGC 6231. We have searched for new cluster members out to a distance of $\sim$ 13 ['arc], extending the Seggewiss area ($\sim$ 8 ['arc]), and we found at least 64 new probable members in this extended field. Differential reddening is clearly measured across the cluster area. We determine the cluster distance (1800 pc) and age ($3.8 \pm 0.6 \times 10^6$ yr). The probable presence of PMS stars and the consequence of this population on the cluster formation history is analysed. We also found that the O8.5III star S161 is a long term variable and we present its light curve extending over more than 20 years. Finally we discuss the existence of Ap stars in the cluster.

Key words: open clusters: individual: NGC 6231 – technique: photometry – stars: formation – stars: pre-main sequence

1. Introduction

Most clusters for which the structure has been studied in detail are older than the Pleiades (about 10^8 yr) and have been subjected to some dynamical evolution. In most cases a mass segregation is observed. There is a large gap in age between these clusters and those which are still embedded in their parental clouds. According to Lada & Lada (1991) there is evidence that forming clusters, still embedded in their giant cloud, already show mass segregation since the brighter stars seem to be more concentrated towards the cluster center at that early stage. Since an open cluster relaxation time is of the order of the crossing time (a few million years), a core-halo structure is likely to be formed in the early stages of the cluster life.

Between the phase of embedded cluster and the state of "exposed" cluster a complex evolutionary process takes place, during which the ambient gas is removed. This process leads to important changes in the structure of the cluster (Verschueren & David 1989; Margulis & Lada 1984; Lada & Lada 1991). What are the observable effects of this dynamical evolution ?

The study of very young open clusters is also essential for improving our understanding of the physics of star formation. Historically, a cluster age has been defined by the best post-MS isochrone fitting the turn-off point at the luminous (most massive) end of the cluster MS. This practice is justified by the generally tight and well constrained upper MS displayed by most young clusters in the Galaxy (e.g. Massey & Thompson 1991; Massey & Johnson 1993). It is, however, interesting to point out that the ensueing nearly coeval picture for massive star formation (say, within a few million yr, but with cases of isolated stars forming earlier by perhaps 5-10 million yr) contrasts with the observed age spread inferred for the less massive, solar or subsolar stellar population still found in its pre-main sequence (PMS) stage of evolution (Cohen & Kuhi 1979). Both the predicted PMS contraction times *and* dispersion in condensation times for the lower mass stars exceed the MS lifetimes of O stars. Indeed, it is not uncommon to infer age spreads as high as 10-20 Myr among low mass stars in a cluster (Adams et al. 1983; Walter et al. 1988). A further pertinent but difficult issue to deal with, may thus be expressed by the following question: how is the observed age dispersion in young open clusters related to stellar masses ?

A related and specially interesting goal in studying very young open clusters has always been to catch the intermediate mass PMS population (the Herbig AeBe stars) on their way to the ZAMS. The only well established case where a large number of intermediate mass stars (up to 10 $M_\odot$) have been identified on their quasi-static contraction towards the ZAMS, concerns the extremely young cluster NGC 6611 in the Ser OB1 association (Hillenbrand et al. 1993), of age about 1.5×10^6 yr. Strong evidence for an intermediate mass PMS population is also present for NGC 2264 of age 3×10^6 yr (Feldbrugge & van Genderen 1991) and turn-on point close to 4-5 $M_\odot$. With an estimated age between 3.2 and 4.5×10^6 yr, NGC 6231 therefore represents one of the best next snapshots in time we presently possess of the evolution of an open cluster, and is a good candidate for hosting some examples of Herbig AeBe stars.

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* Tables 3, 4 and 5 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

NGC 6231 is one of the richest and youngest exposed open clusters known (Mermilliod 1981a; Meynet et al. 1993) and is one of the best objects to study, in spite of its distance and relatively important reddening ($d \simeq 2.0$ kpc, $E(B-V)$ = 0.44 Perry et al. 1991). This cluster, located at l = 343°.5 and b = 1°.2, is found near the southern end of the very young association Sco OB1 and is usually considered as its nucleus (Perry et al. 1991). It contains more than 100 O and B stars according to Shobbrook (1983).

We have completed photoelectric and CCD photometry in the Geneva system out to a radius of $\sim$ 13 [’arc], for 127 and 168 stars respectively. To cover a still larger field we scanned Schmidt plates in three colours with the MAMA (Machine Automatique à Mesurer pour l’Astronomie) developed and operated by CNRS/INSU. By comparison we note that all previous photometric measurments of stars in NGC 6231 were done within a field of maximum radius $\sim$ 8 [’arc] (photoelectric UBV: Westerlund 1959, Bok et al. 1966, Feinstein & Ferrer 1968, Seggewiss 1968, 1969, Schild et al. 1969, 1971, 1974, Garrison & Schild 1979, Dachs et al. 1982, Heske & Wendker 1984, 1985, Kozok 1985, Perry et al. 1990; photographic UBV: Seggewiss 1968; uvby: Crawford et al. 1971 a, 1971b, Morrison 1975, Grønbech & Olsen 1976, Sterken 1977, Shobbrook 1983, Perry et al. 1990, Balona & Laney 1995; Walraven: Walraven & Walraven 1960, van Genderen et al. 1984). Moreover, in spite of this abundant literature there is only photoelectric photometry for 74 stars in UBV, 71 in ubvy and 38 in Walraven.

In this paper we restrict our investigation to the results obtained from the photometry in the Geneva system. Section 2 describes the instrumentation, the observations and the photometric methods employed. In Sect. 3 we report and discuss the results obtained: new candidate members in the cluster corona, differential reddening, cluster distance and age, and the probable presence of PMS stars. Section 4 presents some peculiar objects (a long term variable and a number of candidate Ap stars). The main results are summarized in the final section.

2. Methods

2.1. Instrumentation and observations

Since 1973, the stars in the central part of NGC 6231 (within a radius of $\sim$ 8 [’arc]) have been observed in the Geneva photometric system. Most of these measurements have been done with the photoelectric photometer installed on the 70 cm Swiss telescope at La Silla (Burnet 1976, Bartholdi et al. 1984). The reduction procedures are described in Rufener (1964, 1985).

In 1993 we decided to extend the study to a 7 [’arc] wide corona around the cluster core. These new measurements were done with the photoelectric photometer for stars brighter than V = 13, and with a CCD camera developed at the Geneva Observatory (Blecha et al. 1989) for fainter stars. This camera allows the use of two modes: the standard one (full field) and the selection of subareas in the field. On a non-autoguided telescope, only the second one was usable as it allowed the re-centering of the stars after the exposure in the filters which have enough flux

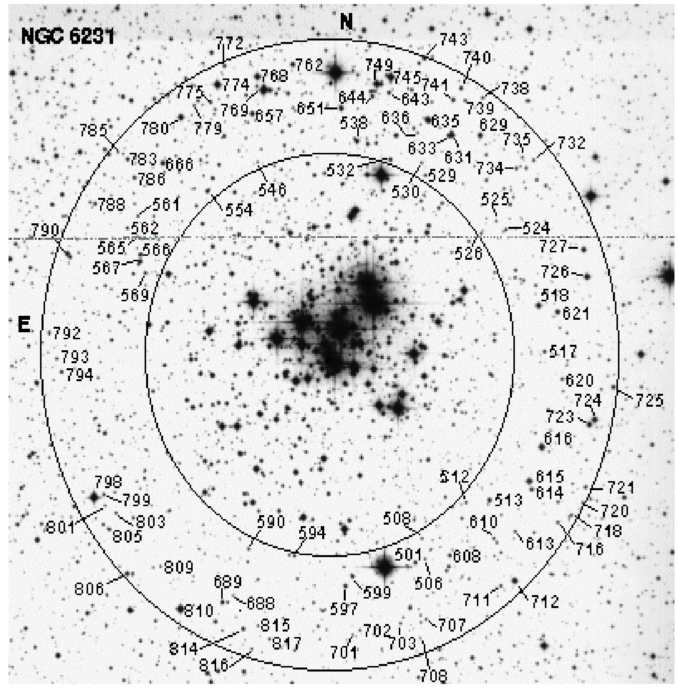

Fig. 1. Identification chart (Scale: $\sim$ 3.1 mm/[’arc]).

(B, V, $V1$ and G). This mode evidently limits the number of stars observable during each exposure. The reduction procedure is described in Bratschi & Blecha (1997) and the link to the Geneva system is achieved through a linear relation, between the values of standard stars reduced in the natural system (CCD) and the values in the Geneva system, corrected by preliminary colour equations (Bratschi 1996). The precision of this reduction procedure is better than 0.02 mag, relatively to the standard Geneva photometric system.

Fig. 1 displays the stars measured in the corona for which at least one reliable measurement has been obtained in each seven colours of the Geneva system. The survey of this corona is complete down to m_V = 13.

In order to be coherent with the numbering used in the database for stars in open clusters (Mermilliod 1988, 1992) we begin the numbering of corona stars with the number 501. Presently 392 stars are recorded in the database, the first 295 being numbered according to Seggewiss (1968) and hereafter referred to as Sxxx.

2.2. The photometric tools

The distance and important reddening of NGC 6231 limits its photometric study by a small telescope (70 cm in our case) to predominantly the upper main sequence (down to about A5V). In that situation, the best way to supplement the analysis via classical colour-magnitude diagrams is the use of calibrations established in the three dimensional X, Y, Z parameter space of the Geneva system.

2.2.1. The X, Y, Z parameter space

The orthogonal X, Y and Z parameters (Cramer & Maeder 1979) are defined in the d, Δ, g (Golay 1973) reddening-free parameter space, where d and Δ measure the Balmer jump with different sensitivities regarding the hydrogen lines, while g compares the hydrogen lines with the Paschen continuum. They are designed to optimise the good separation of photometric temperature and gravity effects achieved in that space and effectively reduce the analysis of B-type stars to a two-dimensional representation (X for $T_{\rm eff}$, Y for log$g$). The Z parameter is very slightly dispersed around zero in that temperature range, and the only significant deviations are related to the Ap spectral character of some of these stars (Cramer & Maeder 1980). The X, Y parameters have been calibrated in terms of $T_{\rm eff}$ and gravity (Cramer & Maeder 1980; Cramer 1984b), MK-types (Cramer 1994a), intrinsic Geneva colours (Cramer 1982, 1993) and intrinsic Johnson $(U, B, V)_0$ colours (Cramer 1984b) as well as the Strömgren β index (Cramer 1984a). Of particular use in the present case is the ability to determine individual colour excesses with good confidence. This is allowed by the fact that the method used (Cramer 1982, 1993) *automatically* accounts for evolutionary effects, since the determination of intrinsic colours is done via the X, Y parameters that are directly related to $T_{\rm eff}$ and log$g$. The potential errors due to other astrophysical effects such as rotation or binarity are also much attenuated for the same reasons. This allows us to define a cleaner intrinsic HR diagram of the upper main sequence, where scatter due to differential reddening within the cluster and in the foreground is greatly reduced. Besides providing an independent estimate of the cluster distance, the determination of absolute magnitudes allowed by the X, Y parameters assists the discussion concerning cluster membership by estimating individual distance moduli. However, instead of using an earlier calibration (Cramer & Maeder 1979), we have preferred to revise the $M_v(X, Y)$ calibration on the basis of a new and more homogeneous set of cluster moduli, and define an improved formulation of the relation (see Appendix).

For the stars lying outside the validity range of the above mentioned calibrations (MK types later than about A2V), a knowledge of their spectral type would be of great help in assessing the probability of membership. This is not the case for NGC 6231 and its neighbouring field, where very few, brighter stars, have been classified. This deficiency can be overcome, however, by the use of "photometric boxes" to estimate an MK type, thus extending the photometric membership criteria.

2.2.2. Photometric boxes

The technique of "photometric boxes" is specific to the Geneva system and depends on its high degree of homogeneity (Nicolet 1981a, 1981b, 1993, 1994). It makes maximum use of the information contained in the photometry by simultaneously using the values measured through the whole set of filters. This is done by considering neighbourhoods in the six-, or less, dimensional space of the colour indices, or else in a three-dimensional parameter space (d, Δ, g or X, Y, Z). If reddening is important, as it is the case here, the photometric neighbourhood is best centred on the d, Δ, g parameters of each star. The distance to the border of the neighbourhood is defined by an appropriate metric which is adjusted to take into account the accuracy of each individual parameter (see Nicolet 1994). The assumption made in this topological approach to multicolour photometry is that the properties of any number of stars lying within the given photometric neighbourhood can be equated with each-other, provided that the radius of the photometric box is small enough. In the present case, we have considered radii of 0.03 mag and limited the search to the 10 closest photometrically similar stars encountered in the entire Geneva data base (presently containing more than 45000 stars). This has allowed us to suggest "photometric spectral types" based on the types encountered in each box, thus providing us with an additional criterion for cluster membership (see Tables 3, 4 and 5). We have also attempted to apply the box method to the CCD data (comparing each CCD measurement with the Geneva photoelectric data base). This has shown us that the provisional standardisation of the CCD system is still not strictly equivalent to that of the photoelectric system, but has nevertheless allowed us to solve a few cases of doubtful membership in the cluster halo.

3. Analysis

3.1. Stellar membership

The results of the analysis of membership are given in Tables 3, 4 and 5. The membership criteria used are based on proper motions, only 15 stars in the PPM and 93 in the study of Braes (1967), and radial velocities (42 bright stars, see references in Raboud 1996, and 53 B-stars, Raboud 1996) as well as on photometric classification.

The distance of the cluster, 1800 pc (see below), renders the accurate measurement of proper motions very difficult. Due to the small separation between the cluster and the field, the proper motion values were used as non-membership criteria only. Three stars (S301, S331 and S336) are classified as non-members following these criteria, but are independently considered as cluster membres via the photometric classification. So we append a question mark following this last interpretation. The radial velocities are limited to the bright stars. Thus it is the photometry that has dominated in the analysis of the 295 stars measured in the Geneva system (photoelectric and CCD).

The photometric analysis was done with two iterations. First, all the stars were examined in the m_V vs $[B_2 - V_1]$, m_V vs d colour-magnitude diagrams and the d vs $[B_2 - V_1]$ and d vs Δ colour-colour diagrams (square brackets are used to distinguish Geneva indices). The different properties of these diagrams allowed us to exclude a number of obvious non-members due to inconsistencies in their relative locations. It was also possible to identify a number of low quality CCD measurements, generally due to a faulty value of the narrow-band filter U, for which no second measurement was available to check the accuracy. Hence the subsequent classification procedure, based on the 7

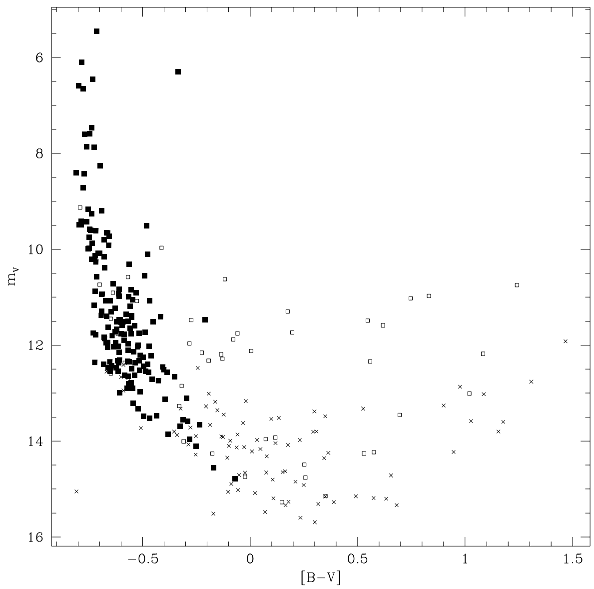

Fig. 2. Color-magnitude diagram containing the raw data. Filled boxes stand for stars considered to be members. Open boxes stand for non-members and the crosses are the non-classified stars (see Sect. 3.1).

Geneva colours, could not be applied to these stars and they will remain *non-classified*. Therefore they do not appear in Tables 3, 4 and 5. But, as their V and B wide-band filter colours are well determined, these stars are reported in the colour-magnitude diagrams (Fig. 2 and 5) and have been considered in the final analysis.

The second iteration consisted in reviewing the remaining sample in the four diagrams but made extensive use of the above-mentioned calibrations in the X, Y diagram (within its validity range), of the X, Y, Z parameter space and of photometric boxes. It was thus possible to identify a number of foreground and background stars via the $M_V(X,Y)$ and MK-type vs X, Y calibrations. For types later than about A2V, the X, Y, Z space (Cramer 1994b) allowed us to classify non-members down to K-type dwarfs and giants, according to their colours. Finally, the application of the photometric box technique to the whole sample enabled us to consolidate the analysis and provided the "photometric spectral type" listed in Tables 3, 4 and 5. Fig. 2 displays the colour-magnitude diagram for all the measured stars in this study. The data are presented before the de-reddening procedure (see Sect. 3.2) and before elimination of non-members.

The global consistency, between the various photometric diagrams and their calibrations, MK-types predicted by the box technique and available dynamical data, led to the qualification of each star as member or non-member. In some cases the selection criteria were not sufficient to decide unambiguously, and we have noted our preferred interpretation followed by a question mark.

In the Seggewiss area we consider 128 stars, among 145, to be members. We have observed 150 stars at larger distances from the center to investigate the cluster extension and have identified 64 likely new members. Down to m_V = 13, the limiting magnitude of the complete photometric survey of the corona, we identify 25 new members. We obtain clear evidence that the contribution of the neighbourhood of the visible stellar cluster to the member population is important, hence indicating the likely presence of a halo surrounding NGC 6231 and tending to confirm the hypothesis of the early stage formation of the core-halo structure.

This is not a surprising result since Kholopov (1969) has revealed the existence of extended halos, or coronas, around the cores of open clusters. Rosvick et al. (1992a,b) reviewed some more recent studies of open cluster coronas, pointing out that an accurate selection of cluster members needs the combined use of photometric, proper motion *and* radial velocity observations.

The availability of the last two kinds of observations is crucial in the case of NGC 6231 if one wants to distinguish between a cluster member and a member of the Sco OB1 association, since NGC 6231 is the nucleus of this association and is therefore at the same distance (Perry et al. 1991). So the determination of the cluster extent using only photometric observations may be a difficult problem. The previously accepted boundaries of NGC 6231 were only based on the *aggregate visible on stellar photographs* (Rosvick et al. 1992a), but the cluster actually extends beyond that borderline, according to this photometric study. However, we could not exclude having considered as cluster members some stars which belong only to the association. To illustrate this problem we will briefly consider the effects of spatial depth.

If we use an angular diameter of 26 ['arc], this corresponds to a linear diameter of 13.3 pc at a cluster distance of 1800 pc. So the effect of the cluster depth on the apparent magnitude of a star will reach a maximum of 0.016 mag, provided we assume that the extinction is uniform across and inside the cluster and that the cluster is spherical. But we know that our determinations of the colour excesses have an accuracy of the order of 0.01 mag (see Sect. 3.2), thus the distance modulus is known at best within 0.03 mag, without taking into account the effects of binaries and stellar rotation which also modify the apparent magnitudes. A precision of 0.03 mag in the distance modulus determination corresponds to the cluster volume surrounded by a spherical shell 5.8 pc thick in which the stars are still considered as cluster members. This shell has a volume more than five times greater than the cluster ! Hence, as NGC 6231 is in close connection with the Sco OB1 association, we may consider too many members belonging to the cluster corona. The difficulty of defining young open cluster borderlines, when these objects are embedded in associations, will depend on the exact location of the cluster and on the geometry of the association. As NGC 6231 is found near the southern end of the association it is likely not totally embedded in Sco OB1. In this case the contamination of the cluster corona by stars belonging only to the association may be less dramatic. Furthermore, if the spatial separation of the successive star generations among the association is sufficiently large, the cluster may be spatially well defined. Nevertheless, the only effective criteria allowing a definitive separation between cluster members and association members is kinematical, as

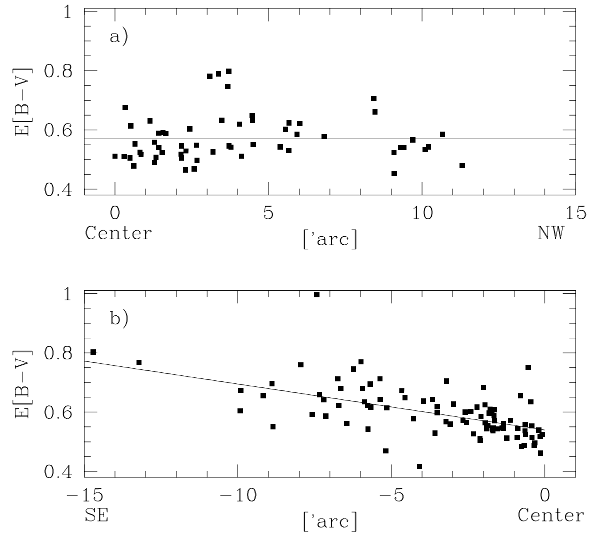

Fig. 3a and b. Reddening in the two parts of the cluster. The star at the top of the second diagram was not taken into account for the fit.

the dispersion in radial velocities of associations reaches 5-7 km s^{-1}, an order of magnitude greater than for open clusters (Efremov 1988).

3.2. *Differential reddening*

The colour excess, $E[B-V]$, is calculated for all the stars falling into the intrinsic colour calibration range (Cramer 1993), and is simply $E[B-V]$ = $[V-B]_0 - [V-B]$ (square brackets distinguish Geneva indices from Johnson indices). We recall here that the Geneva excess is not identical to the Johnson value; we have $E(B-V)_J$ = $0.842E[B-V]_G$ and A_V = $2.75E[B-V]_G$ (Cramer 1984b).

The absorption is constant in the northern part of the cluster, but increases from the center towards the South. A similar trend, although less pronounced, is seen from West to East, but only in the southern part. In order to emphasize this behaviour we tried to define the axis along which the gradient of $E[B-V]$ is maximum. This axis corresponds to the East-West line rotated by 39 degree anticlockwise. In other words, the colour excess increases from the cluster center to the South-East (see Fig. 3). Therefore we could define the trend of $E[B-V]$ across the cluster as follows:

$E[B-V]$ = 0.57 ± 0.01 (se), with a sd of 0.08 if $y_2 \geq 0$
$E[B-V]$ = $-0.01548 y_2$ + 0.54 if $y_2 < 0$.

y_2 is defined as $-x$sin(39°)+$y$cos(39°), where x and y are the original coordinates in arcmin (see Tables 3, 4 and 5).

These equations are used to de-redden all the stars for which we are not able to directly compute an individual $E[B-V]$ value.

The presence of a differential reddening across NGC 6231 was already suggested by Breckinridge and Kron (1963), with a sample of *only* 20 stars. They indicated that most of the reddening occured in the southern part of the cluster. Sanduleak (1968) and, independently, Seggewiss (1969) found an extremely red star (S92, not measured in our study) in the South-East region of NGC 6231. It was shown later that S92 is most likely a normal F5 Ia star lying behind the cluster (Herbig 1972), and suffering a great amount of extinction. Infrared observations (Knacke et al. 1973; Schild et al. 1974) supported this point of view.

Tovmassian et al. (1973), in a survey of the hydrogen content of young stellar clusters, revealed the presence of a neutral hydrogen cloud located in the southern part of NGC 6231. The radial velocity of the cloud, -24 km s^{-1}, is similar to that of t he cluster (around -30 ± 7 km s^{-1}, Raboud 1996). In the northern part of the cluster the cloud seems to be ionized, according to continuum observations at 1410 MHz.

But more recently Shobbrook (1983), in a $uvby\beta$ photometric study of this cluster, considered that the reddening is essentially *uniform across* its field. Van Genderen et al. (1984) studied the Sco OB1 association and divided the region into 6 areas of different average reddening, in which the absorbing material is uniformly distributed (see their Fig. 3 and their Table III). The core of NGC 6231 is considered as moderately reddened (area II). It is surrounded in the north by an area (III) with slightly higher reddenings ($\overline{E(B-V)_J}$ = 0.48 ± 0.04, instead of $\overline{E(B-V)_J}$ = 0.45 ± 0.03), and in the south by the area V, where the highest reddenings occur. Perry et al. (1991), also in a study of the Sco OB1 association, reveal a pronounced north-to-south variation of interstellar reddening across the association, but found a nearly *uniform* reddening *across* NGC 6231 because of its small angular size. Finally Balona & Laney (1995), studying the very central part of the cluster, also observed a fairly uniform absorption across its field.

In our photometric study we have also investigated colour excesses for stars lying beyond the borderline which defines NGC 6231 in van Genderen et al. (1984). Our results agree quite well with the qualitative description they give for the reddening around the cluster. Hence the considered extension of NGC 6231 is a fundamental parameter for the presence of differential reddening.

According to Perry et al. (1991) most of the absorption affecting the cluster is due to interstellar matter within the distance interval from 100 to 1300 pc from the Sun. This is in good agreement with the colour excesses we derive in the direction of NGC 6231 on the basis of the data available in Geneva photometry. Within a field extending to ±10° in galactic coordinates relatively to the cluster (Fig. 4), we note an absence of significant extinction up to 100 pc. Between 100 and 300 pc, the mean visual absorption gradient follows the rather steep value of 3.5 mag kpc^{-1}. With the exception of a few strongly reddened stars, the field then shows a relatively good transparency between about 400 and 1000 pc at a constant value averaging A_V = 0.75 mag. The mean visual extinction of the cluster of about A_V = 1.5 mag is attained, in this extended field, between 1 and 1.2 kpc. If we now restrict the field to ±2°, we find a small number of strongly reddened foreground stars (between about 200 and 600 pc) to the south (in equatorial coordinates) of the cluster, whereas the field absorption gradient averages

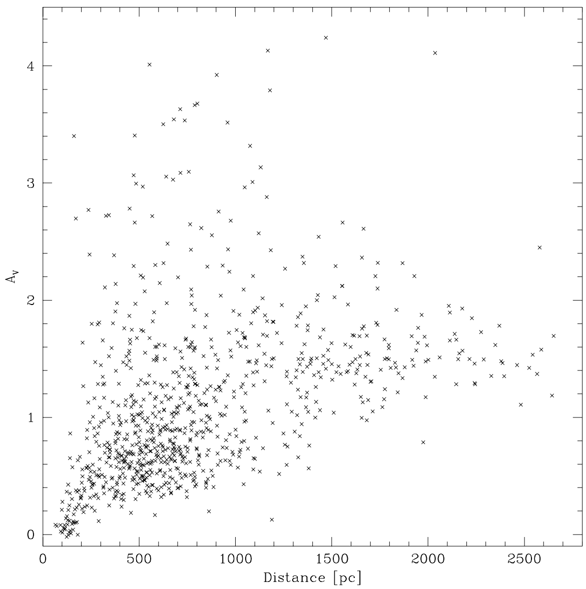

Fig. 4. Variation of the absorption as a function of the distance, in a $\pm 10^\circ$ galactic coordinates field around the cluster.

2 mag kpc^{-1}, reaching the cluster value at about 900 pc, thus implying that most of the extinction occurs in the foreground. The same behaviour still holds within the $1^\circ \times 1^\circ$ field centred on the cluster.

Nevertheless, the presence of the Sanduleak-Seggewiss star in the southern part of the cluster is consistent with the presence of matter at least at the cluster distance. This fact is confirmed by the hydrogen cloud revealed by Tovmassian et al. (1973), and by the study of the interstellar CaIIK line present in the spectra of NGC 6231 star members. Early results of the present study seem to indicate a line component originating in the cluster itself, which could be intensity dependent with the position relative to the center (a forthcoming publication will deal with this problem).

3.3. Cluster distance and age

3.3.1. Distance

We derived individual distance moduli for the same stars as the ones used for the differential reddening study. For these stars we are able to compute the absolute magnitudes (see Appendix) and the de-reddened apparent ones, via the colour excesses. As pointed out in the Appendix, the $M_V(X,Y)$ relation is inadequate for $X < 0.15$ (O to B0 stars). In the case of NGC 6231, however, the correction:

$$-3.254 + 37.153X - 166.29X^2 + 241.21X^3$$

added to the $M_V(X,Y)$ computed for the 16 stars with $X < 0.15$ satisfactorily extends the colour - absolute magnitude calibration. The corresponding estimated M_V in Tables 3, 4 and 5 were corrected with this relation.

We found an average distance of 1757 $\pm$ 370 pc after an iterative gaussian fitting procedure, without taking into consideration stars S243 and 501. This corresponds to a distance modulus of 11.2 $\pm$ 0.4.

To confirm this determination we derived the distance modulus via ZAMS fitting in the $V_0/[B-V]_0$, $m_{v_0}/(B-V)_0$ and $m_{v_0}/(U-B)_0$ photometric diagrams, whereby we used both the Geneva colours with a ZAMS adapted to that system as also the Geneva $[U,B,V]_0$ colours transformed into the Johnson system by the relations given by Cramer (1984b). The aim of this procedure was to check the overall consistency of the transformations.

We used a theoretical ZAMS derived from a "zero age" isochrone based on the models by Maeder, at metallicity Z=0.020 (Schaller et al. 1992). It is very close to the empirical ZAMS by Mermilliod (1981b), but we have preferred to use the theoretical one because it extends further towards the bright magnitudes and is therefore easier to fit to the data. We found $m_0 - M$ to lie between 10.8 and 11.0 for *all* diagrams, which corresponds to a distance between 1450 and 1600 pc. This value is consistent with the modulus derived with the individual magnitude estimates, given the uncertainties over the latter.

In the literature the distances given to NGC 6231 can be grouped into two intervals. The first one includes the smaller distance values, between about 1300 pc and 1650 pc (Mermilliod 1981a; Shobbrook 1983; van Genderen et al. 1984; Balona & Laney 1995). The second one includes the higher distances, between 1800 pc and 2100 pc (Bok et al. 1966; Seggewiss 1968; Feinstein & Ferrer 1968; Schild et al. 1969; Crawford et al. 1971b; Garrison & Schild 1979; Perry et al. 1991). Our results tend to favour the first interval.

3.3.2. Age

The cluster age was estimated with the same photometric diagrams as used for the distance determination. We adjusted isochrones derived from the grids of stellar models, at solar metallicity, computed by Schaller et al. (1992). However, according to Kilian et al. (1994), NGC 6231 shows a lower metallicity than the sun. They found an underabundance of 0.1-0.3 dex with respect to the solar value. But abundance differences of 0.2-0.5 dex may be observed among the individual cluster stars.

As mentioned by Meynet et al. (1993) the presence of binaries in the upper main sequence tends to soften its curvature. It is therefore important to adjust the isochrones only on single stars, otherwise the derived age would be too small. This job is easily done in NGC 6231, as the binary population of the top main sequence is well known (Neubauer 1930, Seggewiss 1974, Levato & Morrell 1983). Once the isochrone is fitted through these single objects, the theoretical envelope of equal mass binaries should encompass at least some of the remaining stars. A few more complex systems may exist and be located above the binary envelope.

With the different colour-magnitude diagrams we derive an age of log$t$=6.5-6.65, i.e. between 3.2 and 4.5 $\times$ 10^6 years. Within each diagram an age spread of 1-2 $\times 10^6$ yr cannot be ruled out, which is consistent with the idea that the majority of the massive members in clusters appear roughly coeval.

As mentioned above, NGC 6231 is known in the literature to be one of the youngest open clusters in the Galaxy. Its age determinations range between 3 $\times 10^6$ (Mermilliod & Maeder 1986) and 6.9 $\times 10^6$ years (Perry et al. 1991). Our result supports the youngest age estimates and is in close agreement with Santos & Bica (1993), who obtained 4.5 $\times 10^6$ years via the study of the integrated spectra of the cluster. These authors also discuss the presence of two WR stars (S220 = HD 152270 and HD 151932) in NGC 6231 and thus infer an age of 3.3 $\times 10^6$ years using massive-star evolutionary models by Maeder (1990), which again is very close to our own determination.

3.4. PMS and age spread

Due to the young cluster age it is very tempting to look for the presence of PMS stars. As our determination of membership was based on the hypothesis that the stars are located within the main sequence band and do not present peculiar physical characteristics (like circumstellar disks), it is possible that non-classified (see Sect. 3.1) or non-member stars could actually be PMS star candidates. We have thus reconsidered all the classifications for stars fainter than m_{v_0} = 11.4. This limiting magnitude was chosen because it corresponds to the brightest value of the log$t$=6.5 PMS isochrone, calculated by Bernasconi (1996) and adjusted to the cluster distance using $m_0 - M = 10.8$. The choice of the youngest age and the smallest distance modulus ensures us to determine the brightest limiting magnitude, and hence to be as complete as possible in our search for PMS star candidates. Each star for which we could not define a photometric spectral type, but has a reasonably good determination of its 7 colours is "converted" into a potential PMS star, and is therefore considered as a cluster member (filled boxes in Fig. 5). The stars which have a photometric spectral type could be considered either as PMS candidates or as non-members. They are represented by open boxes in Fig. 5. Finally we display as crosses the stars which have a definitively doubtful determination of colours, generally in the CCD U filter. As their V and B colours are of better quality we could not exclude a PMS nature for some of these stars. The resulting de-reddened colour-magnitude diagram is shown in Fig. 5.

If a fiducial age of 3.2 $\times 10^6$ yr derived for the upper MS applies to all members of the cluster then, according to theoretical PMS isochrones of Bernasconi (1996), one would expect the turn-on point to lie at late B spectral types, or masses around 2.7 $M_\odot$. As seen in Fig. 5, the region below this isochrone is actually occupied by stars cooler than what is expected for MS stars. Above the 3.2 $\times 10^6$ yr isochrone we observe only a few certified members, though all within the upper envelope defined by the theoretical birthline. The natural explanation therefore is that we are witnessing a flow of 2 to 2.7 $M_\odot$ PMS stars caught in the act of migrating along radiative tracks to the ZAMS (Shobbrook 1983). The mass of the candidates may even be as low as 1.3 $M_\odot$ if we were to consider the few non-classified objects near the limiting magnitude of our search. A lower limit for the age spread among these cluster stars may thus be estimated to be about 7 $\times 10^6$ yr. We note that a well defined "sequence" of candidate PMS stars is also apparent in the recent work of Balona & Laney (1995), although these authors do not venture any hypothesis on its significance.

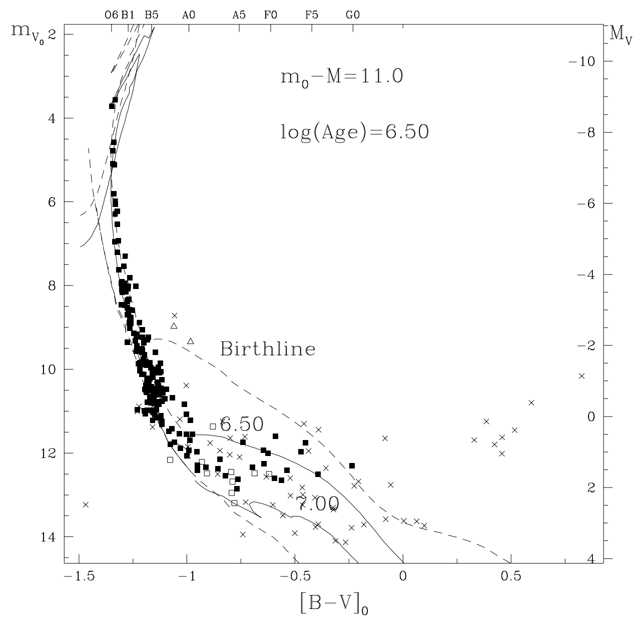

Fig. 5. De-reddened colour-magnitude diagram containing the members (filled boxes) and all the re-considered stars. Open boxes are the PMS candidates for which an alternative explanation exists (foreground or background non-member) and the crosses stand for definitively non-classified stars. A post main sequence isochrone of 3.2 $\times 10^6$ yr is displayed, together with the theoretical envelope of equal mass binaries ($m_{V_0} - 0.75$). Two PMS isochrones (3.2 and 10 $\times 10^6$ yr) are also plotted. The two triangles refer to stars (616 and 806) which could not be eliminated with our criteria.

Of course, a conclusive assertion on the evolutionary status of these stars will necessite more complete observations, including infrared photometry and spectroscopy (de Winter et al. 1997, van den Ancker et al. 1997). At present, the location of the non-classified stars in the diagram of Fig. 5 gives a supplemental criterion for judging of their real nature. In particular, the group of eight stars placed well above and on the right of the birthline are likely non-members. The birthline in fact, far from representing only a rough theoretical prediction, closely reproduces the empirical narrow-band upper limit where low and intermediate mass PMS stars make their first apparition (Palla & Staller 1992).

Althought the purely photometric data available on NGC 6231 do not permit to separate the numerous sources of uncertainty on age and age spreads amongs stellar members, some inferences on the past history of the cluster can nevertheless be attempted. First, the presence of stars as massive as 20-25 $M_\odot$

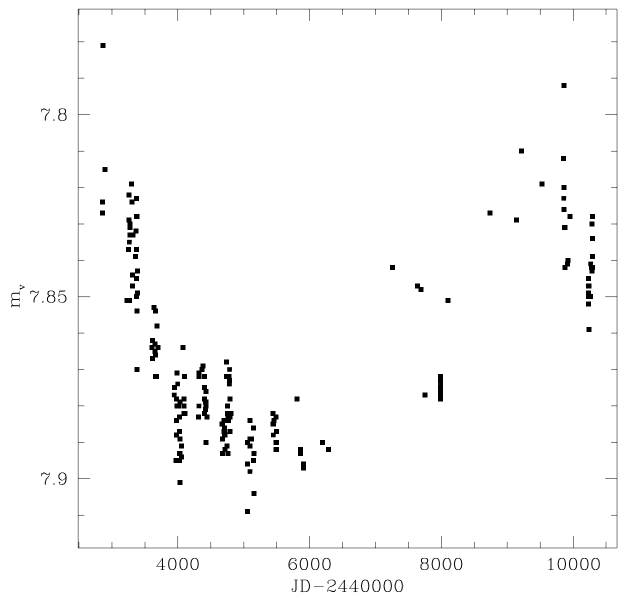

Fig. 6. Light variation for S161 with all observations in the V band. The time interval spans more than 20 years.

and the limited age spread at the top of the MS, are suggestive that O stars were formed during a concentrated burst of star formation less than, say, 3-4 $\times 10^6$ yr ago. Second, the PMS isochrone corresponding to the lower limit 3.2 $\times 10^6$ yr turn-off isochrone rather well reproduces the upper HR envelope of our PMS candidates. The low luminosity stars show a drop in the formation rate at more recent epochs (between the fiducial isochrone and the birthline), and a seemingly continuous formation activity at previous times up to at least 10^7 yr ago. One is therefore tempted to advance that the sudden formation of a group of luminous O stars in the cluster hindered the formation of the less massive ones out of the newly perturbed surrounding medium. Such a non-coeval star formation scenario was outlined by Herbig (1962) and developed in greater details by Norman & Silk (1980).

4. Peculiar stars

4.1. Variability of the star S161

This star, also known as HD 152314, is considered as a O8.5III by Levato & Malaroda (1980) and was recognized as a variable (7.91 $<$ V $<$ 8.12) by Feinstein & Ferrer (1968). It is also recorded in the NSV (New Catalogue of Suspected Variable Stars, Kurkakin et al. 1982) under the number 8027, but is not present in version 4 of the GCVS (General Catalogue of Variable Stars, Kholopov et al. 1985).

In the Geneva system, S161 was considered as a colour standard up to now and has been therefore frequently observed since 1976. The light curve in the V magnitude (Fig. 6) clearly shows a long term variability, with a time scale of about 18 years and peak-to-peak amplitude of 0.07 mag.

The 7 magnitudes of the system display light curves which are identical in shape but have different amplitudes. The effect is maximum for m_U and minimum for m_V. The colours present constant light curves, except U which exhibits the same behaviour as the magnitudes due to the much more pronounced variation of m_U.

The analysis of the different magnitude light curves within a season reveals shorter time scale variations with smaller amplitudes, typically from 0.01 to 0.03 mag.

We therefore have searched for the presence of periodic variations, but have failed to find a coherent solution over the whole sample of measurements. However, we found for three seasons between JD=2443800 and 2445000, a very small amplitude periodic variation. It has a period of 46.2 days with a peak-to-peak amplitude of 0.011 mag. This variation is not confirmed during the other seasons, perhaps due to the smaller amount of data available. It is clear nevertheless, from a qualitative point of view, that light variations do occur at very different time scales, with different amplitudes.

The analysis of colour-magnitude diagrams clearly shows that the star becomes bluer when it brigthens, i.e. $d[U - B]/dm_v > 0$. This tendency is statistically known in the case of Be stars (Nordh & Olofsson 1977, Mennickent et al. 1994), and is most dramatically exhibited in the case of those that undergo shell phases (Cramer et al. 1995, Harmanec 1994). No significant correlation between $[B-V]$ and m_v is observed. The path of S161 in colour-magnitude diagrams reveals qualitatively the same behaviour for every season.

4.2. Photometric peculiar stars

Given the young age of the cluster, it is interesting to search for the presence of Ap stars and estimate, when possible, their type of peculiarity. At least two possible peculiar members, S273 (He weak) and S276 (ApSi ?), are known (Garrison et al. 1979). Strong negative deviations of the Z parameter of Geneva photometry are indicative of peculiarity (Cramer & Maeder 1980), and can serve to point out possible Ap stars in the absence of spectroscopic data. In practice, negative deviations exceeding -0.02 mag in Z relatively to the mean value for normal well measured B and early A-type main sequence stars (Z = 0) are known to be related to the Ap feature. In the case of strong extinction, as in NGC 6231, one must account for a residual effect due to reddening of the Z parameter (Cramer 1993). The correction amounts to +0.013 mag on Z. We have therefore selected those stars with negative deviations exceeding -0.033 in Z and with $Y > -0.06$ (because of the validity range) from both the photoelectric and CCD data. We have furthermore discarded six stars with $X < 0.55$, which is the lower limit observed for ApSi stars (the Z parameter does not significantly detect hotter peculiar stars). The majority of the retained photometric Ap candidates are seen to lie within the range $0.55 < X < 1.2$, i.e. in the temperature range of the ApSi and hottest ApSiCr and ApSrCrEu stars.

Another way of detecting Ap candidates is the use of photometric boxes. Boxes centred on Ap stars are known to predom-

Table 1. Possible Ap stars according to photometric boxes.

Id.	Stars in box	Types encountered in each box		
		ApSi	ApSrCrEu	"Ap"
S86	4	3	-	-
S94	26	-	2	2
S97	27	4	-	2
S126	17	-	2	1
S130	15	4	-	4
S131	59	6	-	2
S168*	21	-	3	2
S199, b	97	5	-	2
S219	18	5	-	1
S278, b	168	1	1	3
S281	1	1	-	-
S302	7	3	-	2
S314, b	66	5	-	1
S337	7	2	-	3
S339, b	94	3	-	2
S344	22	8	-	-
S345	9	3	-	2
629, b	193	3	-	-
643*	18	6	-	-
779*	1	-	1	-
(*=CCD)	(b=box alone)			

inantly contain other Ap stars. We have therefore examined all the boxes (photoelectric and CCD) centred on the stars of Tables 3, 4 and 5 and identified those containing Ap stars among the 10 closest box-neighbours. This has consolidated the detection via the Z parameter, but has also suggested a number of potential Ap candidates with smaller Z deviations. A few stars with large negative Z values do not form boxes, but that can be understood by the fact that their extreme colours isolate them in the d, Δ, g parameter space, putting them outside the 0.03 mag colourimetric sampling range adopted relatively to the other stars in the database.

The results of our selection with the aid of photometric boxes are given in Table 1. The great majority are cluster members, except for S94 and S130 (Table 4) and the possible non-member 779 (Table 5). The first column identifies the star and the presence of a "b" indicates the stars that are detected only by the box method. Column 2 gives the number of stars in the box. Columns 3, 4 and 5 give the types of peculiarity encountered in the box, with their frequency over the 10 first neighbours.

To this table we must add the candidates detected only by the Z parameter, namely: S15, S24, S68, S215, S217 and the CCD measurement of 631. They all lie in the higher temperature range of the ApSi and ApSiCr stars.

We may note that the ApSi peculiarity seems to prevail in our selection. If this result were true, it would bear important physical implications regarding the timescales for the development of Ap characteristics in young clusters. On the other hand, the intrinsically less luminous cooler Ap stars lie at the magnitude limit of our photometry, and are undoubtedly under-sampled in our data, thus precluding a valid statistical analysis in that respect. Furthermore, the proximity to the magnitude limit increases photometric scatter that could render the detection of such later-type peculiarities less significant in the present case. The high reddening of the cluster may also residually influence the parameters, causing some stars to "drift" into photometric boxes containing many Ap stars. This could produce some false detections. We must therefore bear in mind that these "photometrically peculiar" stars must still be confirmed by spectroscopy. The two likely peculiar stars pointed out by Garrison et al. (1979) are not confirmed by our photometric criteria, but S276 is considered only as a marginally peculiar or variable peculiar star and S273 is a He weak star. This kind of peculiarity is only marginally detected with the Geneva photometry (North 1984).

5. Summary

In this photometric study of the very young open cluster NGC 6231 we investigate and discuss some of its important characteristics: structure, reddening, distance and age.

We determine the membership for more than 250 stars in the field of the cluster, and estimate a "photometric spectral type" for more than 200 stars.

We detect the likely existence of a corona around the cluster core, implying a re-definition of the cluster extent and indicating that the mass segregation leading to the core-halo structure is already present close to the emergence of the star cluster from the parental cloud.

We derive a distance of 1757 ± 370 pc and show very clearly that differential reddening occurs across the cluster field. This last result is a direct consequence of the extension of the considered cluster area, larger than in previous studies.

We confirm the very young age of NGC 6231: $3.8 \pm 0.6 \times 10^6$ yr. We give arguments for the presence of PMS candidates of mass less than 2.8 $M_\odot$. Infrared studies are strongly required in order to better characterize their evolutionary status. In that respect an extensive survey of the cluster has been realised in JHK photometry and is under analysis. We have, however, attempted a discussion of the age dispersion and of the cluster history in view of the presence of this PMS population.

We also present observations, obtained over more than 20 years, of a new long term variable (S161), and identify 26 possible Ap stars in the cluster. It would be of great interest to confirm spectroscopically these numerous candidate Ap, as there is a lack of data concerning peculiar stars (Ap, Am) in open clusters in the age range between Orion ($< 1 \times 10^6$ yr) and α Persei (5×10^7 yr) (Abt 1979).

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Table 2. Coefficients of the M_V calibration.

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
-3.773	4.352	-21.615	33.193	0.137	-326.453	179.382	-16.068	-0.590	124.314

Appendix A: a revised absolute magnitude calibration in the X,Y plane

In an earlier paper (Cramer & Maeder 1979), it was shown that a large portion of the X,Y plane could be calibrated in terms of absolute magnitude, providing a quite satisfactory estimator for M_V of the medium to late B-type stars. That calibration has served well up to now in spite of its rather limited spectral range. The absolute magnitudes were derived on the basis of homogeneous cluster distance determinations by Becker & Fenkart (1971) and to which a small correction was applied to account for a better value of the modulus of the Hyades.

Here, we re-examine the question in view of extending the calibration to earlier B-types and to take advantage of more recent cluster distance data. The calibration sample now considered is the study of 30 young solar composition clusters by Meynet et al. (1993). That large sample, with ages between 4×10^6 and 9.5×10^9 years, has the advantage of being homogeneous in both metallicity and in the manner in which the distance moduli were derived. Of the 30 clusters studied by the authors, 18 have been well measured in Geneva photometry and are sufficiently populated in the upper main sequence where the X,Y plane separates temperature and gravity without ambiguity ($Y \geq -0.06$). These are: NGC 457, 581, 1039, 2287, 2516, 2682, 3532, 4755, 5460, 6025, 6231, 6281, 6475, α Per, h Per, χ Per, Orion, and the Pleiades. These clusters provide us with a sample of almost 800 individual absolute magnitudes for stars essentially of classes V to III. We have chosen to fit a cubic polynomial in X and Y to these data, since that form has proven to be well adapted to calibrations in that parameter plane:

$$M_V = a_0 + a_1 X + a_2 Y + a_3 XY + a_4 X^2 + a_5 Y^2 + a_6 XY^2 + a_7 X^2 Y + a_8 X^3 + a_9 Y^3$$

The calibration was carried out by iterations to clean the final sample of undetected binaries and otherwise peculiar stars. The intrinsic luminosity of binaries will, for example, always be underestimated by a calibration based on colours alone, and their distance will be systematically underestimated. The distribution of the residuals of the estimated moduli relatively to the calibration sample will show an asymmetry in favour of smaller moduli in that case. Three iterations, whereby large residuals and negatively biased values were removed finally provided a sample of 483 stars for which the distribution of residuals was reasonably symmetrical. The coefficients a_i corresponding to the relation given above are given in Table 2, providing an absolute magnitude estimator valid over the whole range of B stars of classes V to III. The correlation coefficient is 0.957 and the standard deviation over the 483 estimates is 0.40 mag. This gives a measure of the accuracy, though it also includes the uncertainties over the cluster modulus determinations. In practice, the estimator performs well down to values of $X \geq 0.15$ (types down to B0.5, see Sect. 3.3.1 in the present paper). The M_V of earlier types tend to be overestimated since the relation does not steepen enough with decreasing X. Although the calibration sample contains two supergiants (χ Per 2589 (A2Ia) and χ Per 2227 (B2Ib)) which are well accounted for by the relation, one must be careful in that regard. Estimates of M_V for stars having $Y > 0.15$ and $X > 1.1$ (i.e. probable supergiants) should not be used since the extrapolation will give an overestimated value. The limit $Y \geq$ -0.06 should also be respected. Finally, we must also bear in mind that this calibration is biased in favour of single stars.

References

Abt H.A. 1979, ApJ, 230, 485
Adams M.T., Strom K.M., Strom S.E. 1983, ApJS, 53, 893
Balona L.A., Laney C.D. 1995, MNRAS, 276, 627
Bartholdi P., Burnet M., Rufener F. 1984, A&A, 134, 290
Becker W., Fenkart R. 1971, A&AS, 4, 241
Bernasconi P.A. 1996, A&AS, 120, 57
Blecha A., Weber L., Simond G., Queille D. 1989, ASP Conf. Ser., 8, 192
Bok B.J., Bok P.F., Graham J.A. 1966, MNRAS, 131, 247
Braes L.L.E. 1967, Bull. Astr. Inst. Neth. Suppl., 2, 1
Bratschi P. 1996, Private Communication
Bratschi P., Blecha A. 1997, in preparation
Breckinridge J.B., Kron G.E. 1963, PASP, 75, 248
Burnet M. 1976, Thesis No 232, Ecole Polytechnique Fédérale de Lausanne
Cohen M., Kuhi L.V. 1979, ApJS, 41, 743
Cramer N., Maeder A. 1979 A&A, 78, 305
Cramer N., Maeder A. 1980 A&A, 88, 135
Cramer N. 1982, A&A, 112, 330
Cramer N. 1984a, A&A, 132, 283
Cramer N. 1984b, A&A, 141, 215
Cramer N. 1993, A&A, 269, 457
Cramer N. 1994a, ASP Conf. Ser., 60, 172
Cramer N. 1994b, in *The Impact of Long-Term Monitoring on Variable Star Research*, NATO ASW (Eds. C. Sterken & M. de Groot), Kluwer Academic Publisher, p. 405
Cramer N., Doazan V., Nicolet B., de la Fuente A., Barylak M. 1995, A&A, 301, 811
Crawford D.L., Barnes J.V., Golson J.C. 1971a, AJ, 76, 621
Crawford D.L., Barnes J.V., Hill G., Perry C.L. 1971b, AJ, 76, 1048
Dachs J., Kaiser O., Nikolov A., Sherwood W.A. 1982, A&AS, 50, 261
Efremov Yu. N. 1988, Sov. Sci. Rev. E. Astrophys. Space Phys., 7, 105
Feinstein A., Ferrer O.E. 1968, PASP, 80, 410
Feldbrugge P.T.M. and A.M. van Genderen 1991, A&AS, 91, 209
Garrison R.F., Schild R.E. 1979, AJ, 84, 1020

Golay M. 1973, Vistas Astron., 14, 13
Grønbech B., Olsen E.H. 1976, A&AS, 25, 213
Harmanec P. 1994, *The Impact of Long-Term Monitoring on Variable Star Research*, NATO ASW (Eds. C. Sterken & M. de Groot), Kluwer Academic Publisher, p. 55
Herbig G.H. 1962, ApJ, 135, 736
Herbig G.H. 1972, ApJ, 174, L89
Heske A., Wendker H.J. 1984, A&AS, 57, 205
Heske A., Wendker H.J. 1985, A&A, 151, 309
Hillenbrand L.A., Massey P., Strom S.E., Merrill K.M. 1993, AJ, 106, 1906
Kolopov P. N. 1969, SvA, 12, 625
Kholopov P.N., Samus N.N., Frolov M.S., Goranskij V.P., Gorynya N.A., Kireeva N.N., Kukarkina N.P., Kurochkin N.E., Medvedeva G.I., Perova N.B., Shugarov S.Yu. 1985, General Catalogue of Variable Stars (Ed. P.N. Kholopov), Moskow ”Nauka” Publishing House
Kilian J., Montenbruck O., Nissen P.E. 1994, A&A, 284, 437
Knacke R. F., Strom K. M., Strom S. E. 1973, ApJ, 179, 493
Kozok J.R. 1985, A&AS, 61, 387
Kukarkin B.V., Kholopov P.N., Artiukhina N.M., Federovich V.P., Frolov M.S., Goranskij V.P., Gorynya N.A., Karitskaya E.A., Kireeva N.N., Kukarkina N.P., Kurochkin N.E., Medvedeva G.I., Perova N.B., Ponomareva G.A., Samus’ N.N., Shugarov S.Yu. 1982, New Catalogue of Suspected Variable Stars (Ed. B.V. Kukarkin), Moskow ”Nauka” Publishing Office
Lada C. J., Lada E. A. 1991, ASP Conf. Ser., 13, 3
Levato H., Malaroda S. 1980, PASP, 92, 323
Levato H., Morrell N. 1983, ApL, 23, 183
Maeder A. 1990, A&AS, 84, 139
Margulis M., Lada C.J. 1984, Occ. Rep. R. Obs. Edin., 13, 41
Massey P., Thompson A.B. 1991, AJ, 101, 1408
Massey P., Johnson J. 1993, AJ, 105, 980
Mennickent R.E., Vogt N., Sterken C. 1994, A&AS, 108, 237
Mermilliod J.-C. 1981a, A&AS, 44, 467
Mermilliod J.-C. 1981b, A&A, 97, 235
Mermilliod J.-C., Maeder A. 1986, A&A, 158, 45
Mermilliod J.-C. 1988, Bull. Inform. CDS, 35, 77
Mermilliod J.-C. 1992, Bull. Inform. CDS, 40, 115
Meynet G., Mermilliod J.-C., Maeder A. 1993, A&AS, 98, 477
Morrison N.D. 1975, ApJ, 200, 113
Neubauer F.J. 1930, PASP, 42, 235
Nordh H.L., Olofsson S.G. 1977, A&A, 56, 117
Norman C., Silk J. 1980, ApJ, 238, 158
North P. 1984, Thesis No 2117, Geneva University, p. 210
Nicolet B. 1981a, A&A, 97, 55
Nicolet B. 1981b, A&A, 104, 185
Nicolet B. 1993, in *Poster Papers on Stellar Photometry*, IAU Coll. 136, 17 (Eds. Elliott I. & Butler C.J.) Dublin Institute for Advanced Studies
Nicolet B. 1994, ASP Conf. Ser., 60, 182
Palla F., Staller S.W. 1992, ApJ, 392, 667
Perry C.L., Hill G., Younger P.F., Barnes J.V. 1990, A&AS, 86, 415
Perry C.L., Hill G., Christodoulou D.M. 1991, A&AS, 90, 195
Raboud D. 1996, A&A, 315, 384
Rosvick J.M., Mermilliod J.-C., Mayor M. 1992a, A&A, 255, 130
Rosvick J.M., Mermilliod J.-C., Mayor M. 1992b, A&A, 259, 720
Rufener F. 1964, Publ. Obs. GenŁve, A, 66, 413
Rufener F. 1985, in *Calibration of Fundamental Stellar Quantities*, IAU Coll. 111, 253 (Eds. D.S. Hayes et al.) Reidel Publ. Co., Dordrecht
Sanduleak N. 1968, ApJ, 151, L45
Santos J.F.C., Bica E. 1993, MNRAS, 260, 915
Schaller G., Schaerer D., Meynet G., Maeder A. 1992, A&AS, 96, 269
Schild R.E., Hiltner W.A., Sanduleak N. 1969, ApJ, 156, 609
Schild R.E., Neugebauer G., Westphal J.A. 1971, AJ, 76, 237
Schild R.E., Oke J.B., Searle L. 1974, ApJ, 188, 71
Seggewiss W. 1968, Veröff. Astron. Inst. Univ. Bonn. No. 79
Seggewiss W. 1969, AJ, 155, L1
Seggewiss W. 1974, A&A, 31, 211
Shobbrook R.R. 1983, MNRAS, 205, 1229
Sterken C. 1977, A&A, 57, 361
Tovmassian H.M., Nersessian S.E., Shahbazian E.T. 1973, Aust. J. Phys., 26, 853
van den Ancker M.E., Thé P.S., Feinstein A., Vázquez R.A., de Winter D., Pérez M.R. 1997, in press
van Genderen A.M., Bijleveld W., van Groningen E. 1984, A&AS, 58, 537
Verschueren W., David M. 1989, A&A, 219, 105
Walraven Th., Walraven J.H. 1960, Bull. Astr. Inst. Neth., 15, 67
Walter F.M., Brown A., Mathieu R.D, Myers P.C., Vrba F.J. 1988, AJ, 96, 297
Westerlund B.E. 1959, PASP, 71, 156
de Winter D., Koulis C., Thé P.S., van den Ancker M.E., Pérez M.R., Bibo E.A. 1997, A&AS, 121, 223

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