v. Mexicana Astron. Astrof., 6, 173-180 (1981)

PROPERTIES OF G-TYPE STARS FROM *uvby* PHOTOMETRY

A. Ardeberg and H. Lindgren

European Southern Observatory and Lund Observatory

RESUMEN

A raíz de los muchos aspectos interesantes conectados con los estudios de estrellas de tipo espectral G, hemos hecho una investigación preliminar sobre lo conveniente que es el sistema fotométrico *uvby* para estas estrellas. Por lo menos para aquellas de la secuencia principal y de la rama de las gigantes, la resolución en gravedad y temperatura derivada del sistema *uvby* parece ser mejor que la derivada de la clasificación MK de alta calidad. Para estas mismas estrellas, la resolución del sistema *uvby* con respecto a metalicidad, parece muy apropiada. Se han hecho comparaciones con relaciones color-color basadas en modelos en el sistema *uvby*. Si bien las propiedades básicas de estas relaciones ya han sido confirmadas, algunas correcciones parecen necesarias tanto con respecto a los parámetros de gravedad como a los de metalicidad basados en modelos. Se ha detectado un número considerable de estrellas de tipo espectral G de la población II intermedia, que pertenecen tanto a la secuencia como a la rama de las gigantes. Al mismo tiempo, parece ser que las estrellas de la rama horizontal roja son sumamente escasas, por no decir totalmente inexistentes en la la vecindad solar. La abundancia relativamente alta de estrellas de la población II intermedia que pertenecen a la secuencia principal y a la rama de las gigantes, constituye una confirmación de modelos recientes vinculados con la evolución de estrellas de la población II. La ausencia de estrellas en la rama horizontal roja implica fuertemente que la población II intermedia no produce ninguna rama horizontal significativa. En este trabajo se trata la relación existente entre esta misma población y las estrellas de tipo solar y las del halo.

ABSTRACT

Because of the many interesting aspects attached to the study of stars of spectral type G, a preliminary investigation has been made of the suitability of the *uvby* photometric system for such stars. At least for stars on the main sequence and the giant branch, the gravity and temperature resolution from *uvby* photometry seems better than that obtained from high-quality MK classification. For the same stars, the resolving power of the *uvby* system with respect to metallicity seems very good. Comparison have been made with model-based colour-colour relations in the *uvby* system. Whereas the basic properties of these relations are confirmed, certain corrections seem necessary both concerning the gravity and the metallicity model-based parameters. A considerable number of G-type stars of intermediate population II is found, belonging to the main sequence as well as to the giant branch. At the same time, red horizontal-branch stars seem to be extremely rare in the solar neighbourhood if they are present at all. The relatively high number of intermediate population II stars on the main sequence and the giant brach confirms recent models for the evolution of population II stars. The absence of red horizontal-branch stars strongly indicates that the intermediate population II does not produce any significant horizontal branch. The relation of this population to the solar-type stars and to the halo stars is discussed.

Key words: PHOTOMETRY – ABUNDANCES – STARS-HORIZONTAL BRANCH – STARS-POPULATION II

I. INTRODUCTION

The intermediate-band photometric *uvby* system de- ıed by Strömgren (1963*a*, *b*; 1966) was originally tended only for stars of spectral types A and F. hereas it has been fairly extensively calibrated and ed for stars of earlier spectral types (Crawford 1978), tle corresponding work has been undertaken for stars ith spectral types later than G0. The only calibration ork undertaken in this respect seems to be that of gen (1976, 1978) on a system related to, but different om, the Strömgren *uvby* system.

This may seem surprising form many points of view. ıe major spectral features measured in the *uvby* stem, the Balmer discontinuity and the influence of metal lines as well as the measurement of the (pseudo) continuum, should remain at least reasonably valid also for stars of spectral types considerably more advanced than the solar type. From model data this has also been shown to be the case (Gustafsson and Bell 1979). Furthermore, stars with spectral types later than F are particularly useful for many types of studies. They are very abundant. Also, they are still around as representatives of the oldest stellar populations. They comprise a giant population more or less readily observable even in many globular clusters. They provide an opportunity to study clump stars.

The present paper is a preliminary report on an attempt to deduce some properties of stars with spectral types later than G0 using the *uvby* system.

II. STARS OBSERVED

For observing we selected basically three samples of stars. The first one was chosen to comprise MK standards of high quality in order to calibrate the indices describing gravity and temperature. Efforts were made to cover both parameters as well as possible. The aim was to obtain a good coverage in temperature starting at the value corresponding to F5 V and to reach at least the temperature value corresponding to K0 III. On the low-temperature side main-sequence MK standards are scarce. For the high-temperature side the same is true (for natural reasons) for giant stars. Also, supergiant stars are rare throughout all the temperature interval studied, especially so since the aim was to select only those stars not showing significant effects of interstellar absorption.

The second sample of stars was chosen to provide a grid of [Fe/H] values versus temperature. Again, efforts were made to cover both parameters as extensively as possible. For the present work, for [Fe/H] standards we have made use only of abundance determinations from spectrograms of reasonably high resolution. The existing sample of such standards is not rich, especially not so for intermediate and lower temperatures and for lower metal abundances.

The third sample was one of brighter G-type stars. This sample was intended to give a first impression of the statistical properties of the G-type stars as derived from *uvby* photometry.

III. OBSERVATIONS

The observations discussed in the present paper were made at the European Southern Observatoty (ESO) at Cerro La Silla in Chile, with the 0.5-m Copenhagen reflector, in the Cassegrain focus equipped with a simultaneous four-channel *uvby* grating photometer of the Strömgren type (Grønbech *et al.* 1976). Both the telescope and the photometer are available part-time to ESO. Uncooled EMI 6256 photomultipliers and pulse counting were used together with standard *uvby* filters (Crawford 1966; Crawford and Barnes 1970) placed after pre-selecting slots.

Every star measurement consisted of several star and sky integrations together with sky measurements close to the star. A single integration covered between 2 and 16 seconds. A measuring diaphragm of 30 seconds of arc was used throughout. For practically all stars included and all three colour indices the resulting standard deviation for a single measurement is well below 0.010 mag. The limiting magnitude of the present data is $B = 10.2$.

IV. EFFECTS AND RESTRICTIONS IMPOSED BY INFLUENCE OF INTERSTELLAR ABSORPTION

Interstellar absorption affects the *b-y* as well as the c_1 and m_1 colour indices. Assuming the interstella absorption curve to be essentially universal, one ma correct the c_1 and m_1 indices, using for instan empirical correction formulae with *b-y* as paramet (Crawford, 1975*a*; Crawford and Mandwewala, 1976 However, as this method largely implies sacrificing t *b-y* index, such corrected c_1 and m_1 values have not bee derived in the present paper.

Tests on samples of stars with identical MK types an varying apparent magnitudes have shown that t distance-modulus range covered by standard stars luminosity classes III-V and the great majority of t field stars is quite safe from significant effects interstellar absorption. This is certainly not true for t super-giant stars. For these stars, modest restrictio with respect to effects of interstellar absorption tend reduce the material at hand in such a way that only ve tentative conclusions can be drawn. From a statistic point of view this is hardly very serious. Accordingly, the following discussion we have largely omitted t supergiant stars. Still, some of their large-scale properti will be mentioned briefly.

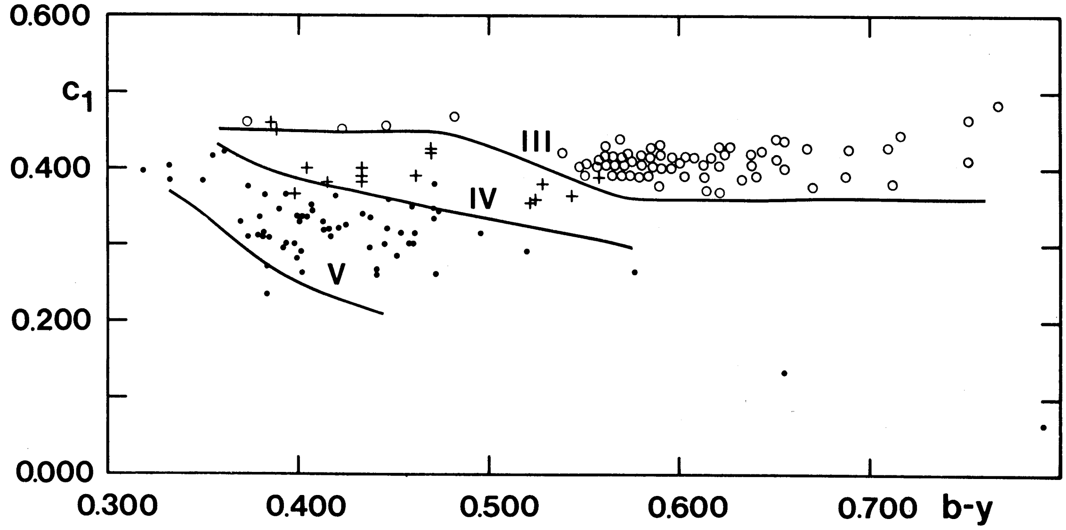
V. THE GRAVITY-VERSUS-TEMPERATURE DIAGRAM

In this first attempt to establish relations betwe gravity and temperature we have used MK class exclusively. With the purpose in mind of arriving at system as consistent as possible, we have only used M classifications from Keenan and Pitts (1980), Morg and Keenan (1973), and Johnson and Morgan (1953). total of 148 stars are included.

Figure 1 displays the result, including tentat luminosity-class separation lines. The discriminati power with respect to gravity seems quite good. Especi ly striking is the narrow horizontal relation defin by stars of luminosity class III. For the coolest sta included in Figure 1 the gravity resolution indicated considerable. This may seem rather surprising. Certainl the effect cannot be attributed to the influence of t Balmer discontinuity, taking into account the lo temperatures involved. However, before discussing p sible explanations we prefer to improve the scarce da at hand for the main-sequence stars of lowest tempe tures. The corresponding observations are in progress.

In Figure 2 we test the model-based relation for gia stars given by Gustafsson and Bell (1979) against o observed relation for stars of luminosity class I Obviously, the model relations are too low in c_1. T was also concluded by Gustafsson and Bell (197 Given such a zero-point adjustment there is considera indication that the giant branch from early G-typ down to, at least, temperatures corresponding to K1 I defines quite a narrow interval in gravity.

It is of special interest to note the region for r horizontal-branch stars. Especially after the zero-poi shift of the model-based relations this region see completely empty. This is also true for the "47-Tucan



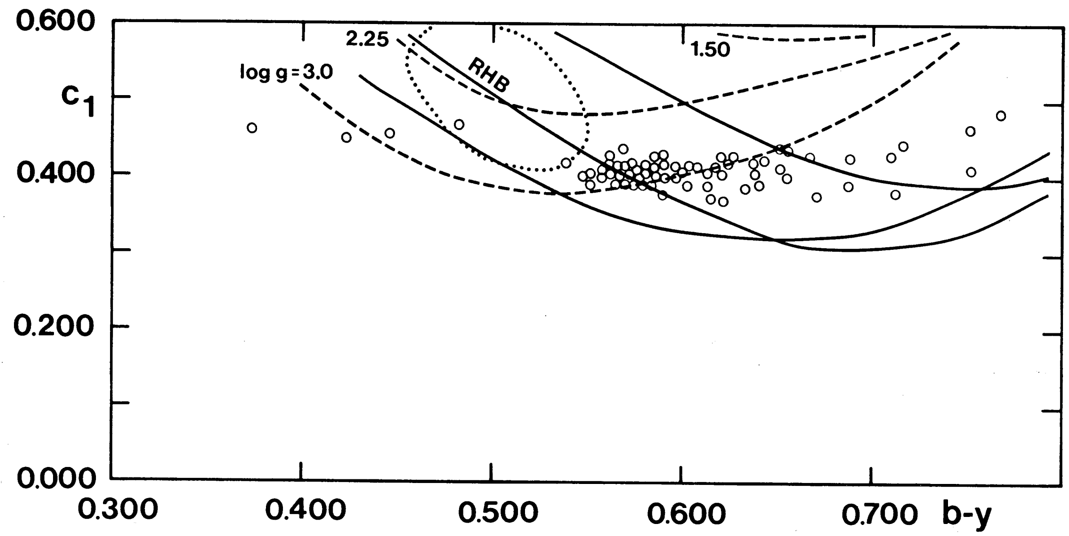
g. 1. c_1 plotted versus *b-y* for 148 MK standard stars of luminosity classes III-V. Small filled circles denote stars of luminosity class V, osses those of luminosity-class IV and open circles stars of luminosity class III. Our tentative luminosity-class separation lines have en indicated.

›pulation" red horizontal-branch stars (Gustafsson and rdeberg 1978; Ardeberg and Gustafsson 1981).

For a few super-giant stars observed the effects of terstellar absoption are only relatively limited. The ıta for these stars indicate that in the (b-y; c_1) diagram ey define a relation progressing from the upper ft-hand part of Figure 1 to its lower right-hand side.

VI. THE METALLICITY-VERSUS-TEMPERATURE DIAGRAM

For the present study of the metallicity discrimination in the *uvby* system for G-type stars, we have used the compilations of Cayrel de Strobel *et al.* (1980) and Bartkevičius (1980). To arrive at some tentative conclusions we have accepted, for the time being, straight mean values of all compiled [Fe/H] values for all the stars involved, based on high-dispersion spectrograms. In order to check for effects of luminosity class we first plotted m_1 versus *b-y* for stars with well determined MK classes (Keenan and Pitts 1980; Morgan and Keenan 1973; Johnson and Morgan 1953; Morgan *et al.* 1943; Landi *et al.* 1977; Keenan and Keller 1953; Morgan and



;. 2. Comparison in the (c_1 ; *b-y*) diagram between the model-based relations given by Gustafsson and Bell (1979) for giant stars and r observational data for stars of luminosity class III. Full-drawn curves represent models for [Fe/H] = 0.0, dashed curves models for ɜ/H] = −1.0. The position of red horizontal-branch (RHB) stars is indicated.

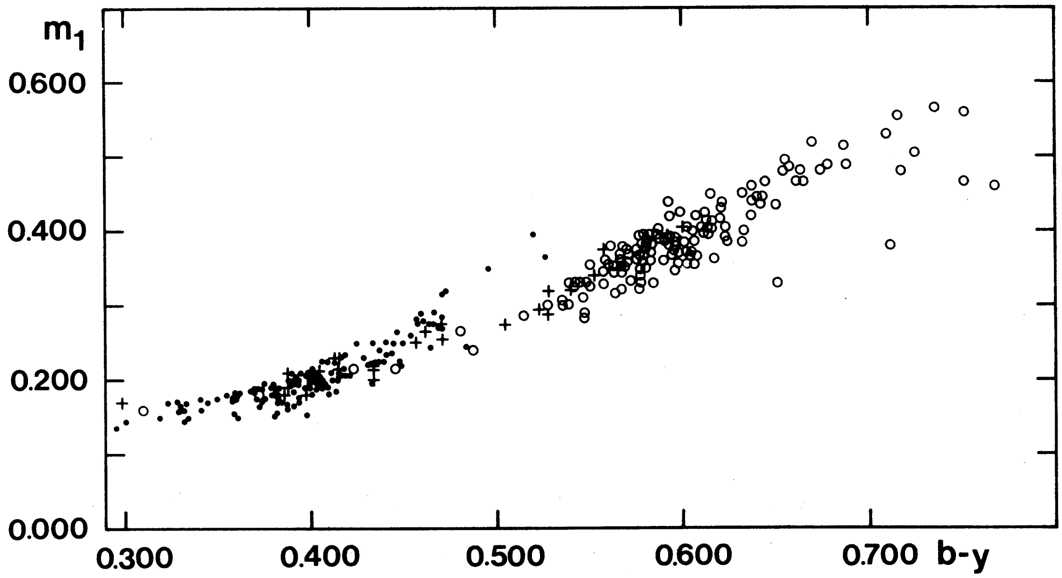


Fig. 3. m_1 plotted versus *b-y* for 306 stars with MK classes of high weight. Significance of symbols is the same as in Figure 1.

Roman 1950; Morgan *et al.* 1953; Greenstein and Keenan 1958; Abt 1958).

The resulting diagram is shown in Figure 3 from a total of 306 stars. A dependence on luminosity class is clearly visible. This has to be carefully taken into account for our further discussion. At the same time, it is of no major consequence for the resolving power of the system, as it has been demonstrated above that luminosity classes may be readily obtained from the *b-y* and c_1 indices. In Figure 4 we give the tentative relation between m_1 and *b-y* for a total of 29 stars wit metallicity similar to that of the sun. The separation (the relations for main-sequence and giant stars is agai confirmed. It is further noted that whereas the mai sequence stars defined a very narrow relation, this is n(the case for the giant stars.

The relations between m_1 and *b-y* for 57 stars (non-solar metallicities are displayed in Figure 5. W conclude that the resolving power of the *uvby* syste with respect to metallicity seems quite good for G-ty

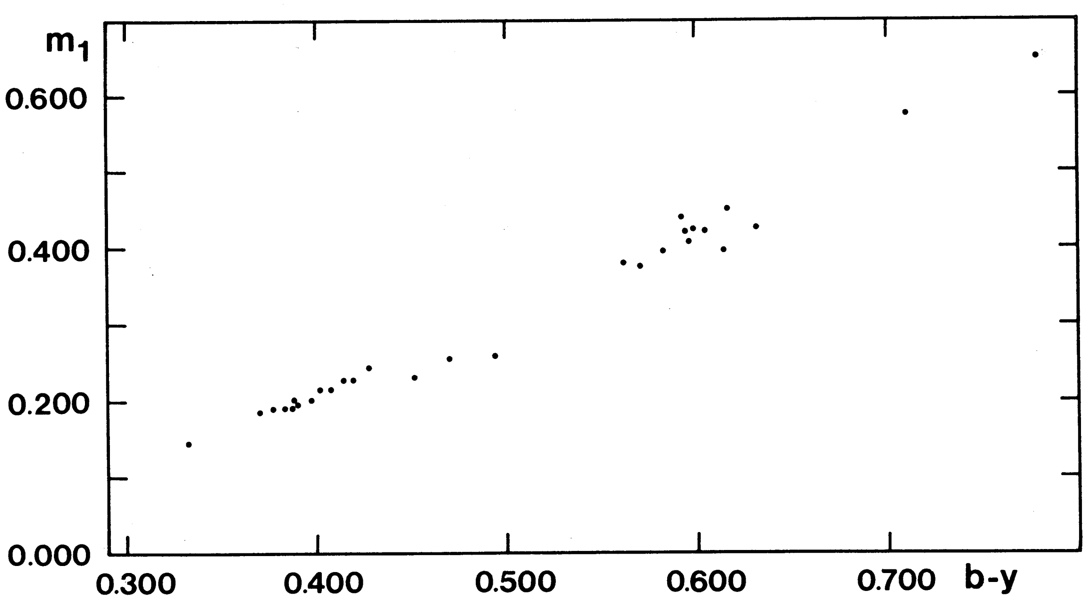


Fig. 4. m_1 plotted versus *b-y* for 29 stars with $-0.1 < [Fe/H] < +0.1$.

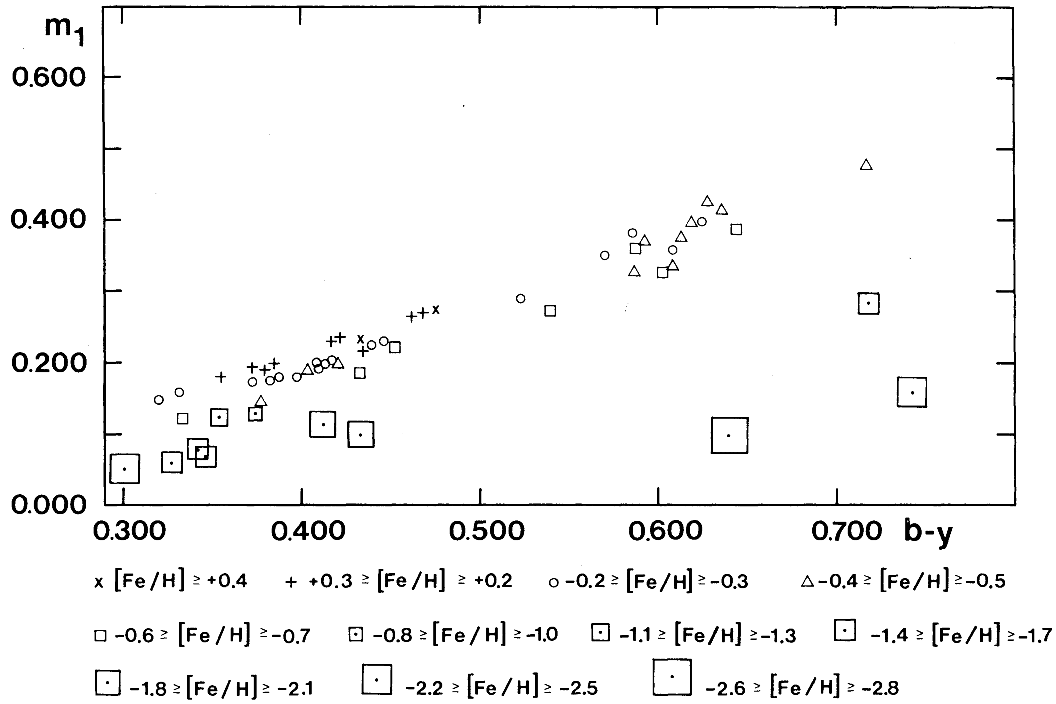


Fig. 5. m_1 plotted versus *b-y* for 57 stars with non-solar metallicities.

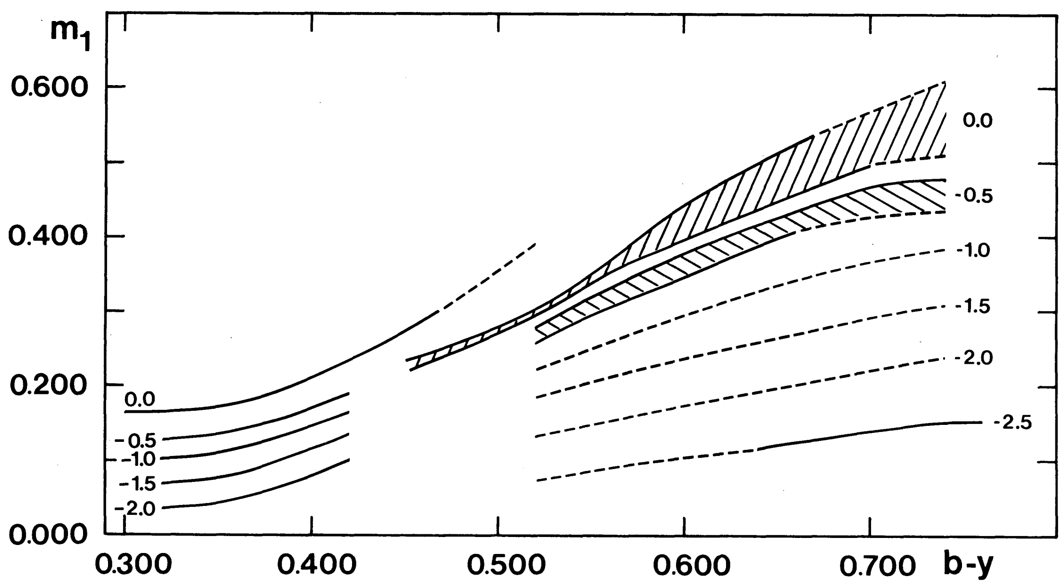


Fig. 6. Our tentative metallicity calibration in the (m_1 ; *b-y*) diagram. The [Fe/H] values are indicated.

stars and stars of early K-type.

Our resulting tentative metallicity calibration is shown in Figure 6. The (m_1; [Fe/H]) gradient seems quite favourable especially for G-type giant stars.

Figure 7 shows our test of the model-based relations between m_1 and *b-y* given by Gustafsson and Bell (1979) and, according to these authors, valid for a wide range in gravity. For comparison, we have used all of our results from Figures 4 and 5. First, we conclude that the model-presumed insensitivity to gravity seems too optimistic. It is furthermore noticed that whereas for the high-temperature part of the diagram the model m_1 values should be decreased for stars of solar metallicity; the contrary seems to hold for the low-temperature part

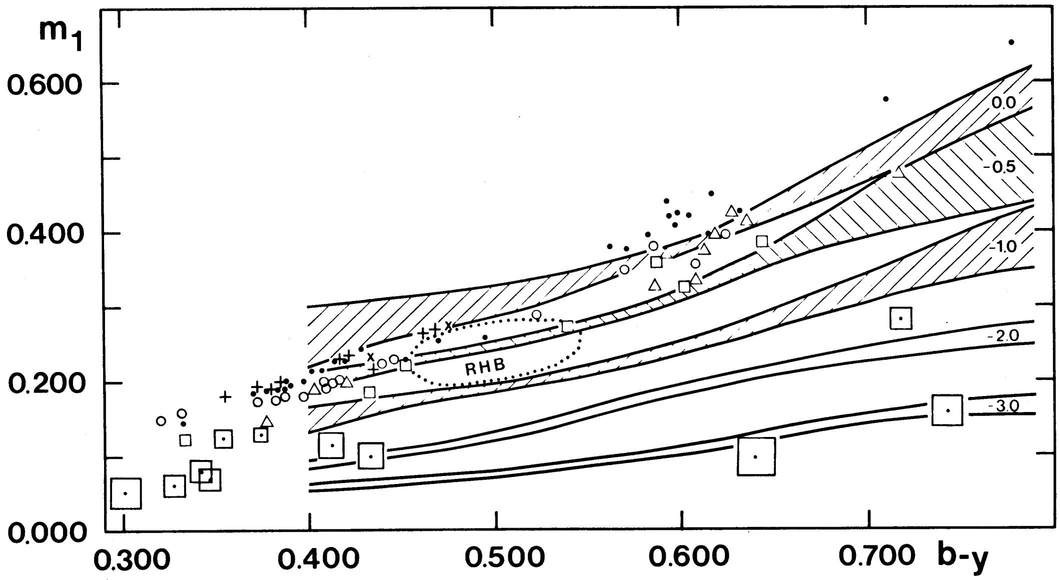


Fig. 7. Comparison in the (m_1; *b-y*) diagram between the model-based relations given by Gustafsson and Bell (1979) and our observational data. Significance of symbols is the same as in Figures 4 and 5.

of the diagram. In this respect it should be pointed out that our relation for solar-type stars transfers very smoothly into the relation or stars of late F-types (Crawford 1975*b*).

Given the zero-point shifts discussed above, the model-suggested dependence on metallicity seems well supported by observations. The red horizontal-branch stars will be discussed below.

From Figure 7 it follows that for main-sequence stars of solar temperature, our values of d[Fe/H]/dm_1 are smaller than those suggested by the corresponding models. For the cooler giants stars involved, the situation is the opposite. For stars with *b-y* around 0.35, corresponding roughly to spectral type F8 V, we may compare our d[Fe/H]/dm_1 value to that given by Nissen (1981). Our value is 13.3, whereas Nissen obtains d[Fe/H]/d$m_1|_{b\text{-}y}$ equal to 13.6.

The few available super-giant stars with only limited influence of interstellar absorption indicate a generally high m_1 level, especially for lower temperatures.

We add that the present material does not permit any firm conclusions regarding the behaviour of stars with abundance anomalies such as CNO over-abundance. The tendencies indicated need further observational support. Observations of stars with well-determined abundance anomalies are in course.

VII. THE TOTAL SAMPLE OF STARS OBSERVED

For all stars observed except for known super-giant stars we give in Figure 8 the data in the gravity vs. temperature diagram. Our tentative luminosity-class separation lines have been entered. The giant relation seems well-confirmed. Taking into account the limiting magnitude, the relative abundances of the luminosity classes V, IV and III are close to what one would expect from a statistical sample. We note the abrupt effect of the Hertzsprung gap.

In Figure 9 we display the relation between metallicity and temperature for the same stars shown in Figure 8. Our tentative metallicity sequences are outlined. For main-sequence and giant stars of solar metallicity the sequences are well-defined. The number of stars of intermediate population II is quite pronounced, whereas the stars of extreme population II are only sparsely represented. The latter fact is quite natural if the limiting magnitude is taken into account. Referring to the intermediate population II we adopt the definition given by Strömgrem (1966), i.e., the population covering the interval corresponding to $-0.8 <$ [Fe/H]< -0.3. Here the [Fe/H] = [Fe/H](Δm_1) calibration is taken from Nissen and Gustafsson (1978) and the [Fe/H] value for the Hyades is adopted from Gustafsson *et al.* (1974).

VIII. DISCUSSION

The tentative results of the present study already give clear indications of the usefulness of the *uvby* system for three-dimensional classification of stars with spectral types down to, at least, early K type. The present data seem to suggest that the (c_1; *b-y*) diagram could give a gravity resolution better than that provided by the MK classification system. We have in progress a corresponding study based on stars with trigonometric parallaxes. Our data as applied to the (m_1; *b-y*) diagram

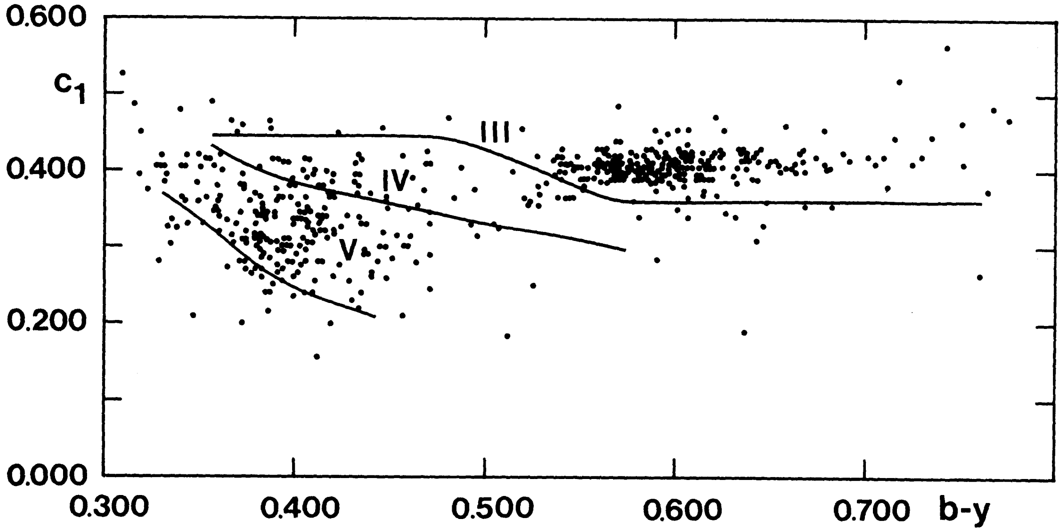


Fig. 8. Complete observed sample of stars plotted in the (c_1 ; b-y) diagram. Luminosity-class separation lines are as in Figure 1.

ıdicate a high resolving power for the metallicity of ;-type stars.

The relative abundance of stars of intermediate opulation II is of some interest. For F-type stars the ɜlative number of stars of intemediate population II is round 0.10 as compared to that of solar-type stars Gustafsson and Ardeberg 1978). According to Renzini 1977) the intermediate population II has relatively ıore stars of G-type than of F-type. Therefore, the opulation distribution found in the present study may e considered as a confirmation of the models of stellar volution presented by Renzini (1977). In this connection it is of further interest to compare the abundance ratios defined by intermediate population II and population I for G-type stars on the main sequence and on the giant branch. However, the numbers indicated in Figure 9 need further confirmation before any relevant conclusions may be drawn.

It seems quite clear that our results point to a remarkable absence of red horizontal-branch stars. This must, of course, be compared with the relatively large numbers of stars of intermediate population II found on the main sequence and giant branch. At the same time, all known globular clusters with (relatively) high metal

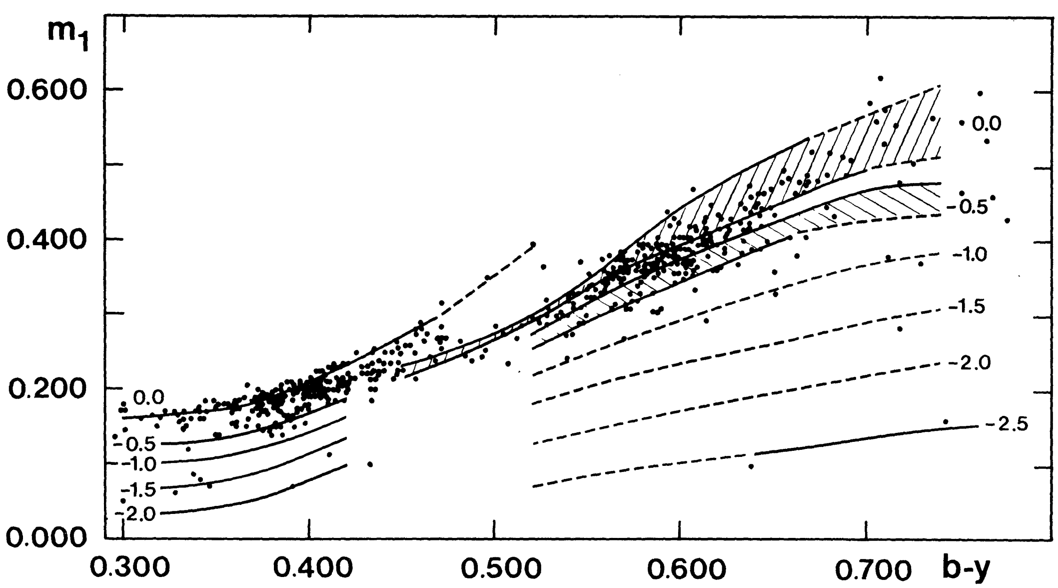


Fig. 9. Complete observed sample of stars plotted in the (m_1 ; b-y) diagram. Metallicity calibration is as in Figure 6.

abundances display well-defined red horizontal branches. Good examples are 47 Tuc and M71. In fact, these clusters have as many red horizontal-branch stars as giant stars with comparable luminosity (Gustafsson and Ardeberg 1978; Ardeberg and Gustafsson 1981). It may therefore be concluded: Firstly, that the absence of red horizontal-branch stars in our complete sample is quite significant. Secondly, it seems well-indicated that the intermediate population II does not produce any considerable red horizontal branch stars. Thirdly, the present results support earlier investigations of 47 Tuc (Gustafsson and Ardeberg 1978; Pilachowski *et al.* 1980; Keith and Butler 1980; Ardeberg and Gustafsson 1981) and of M71 (Bell and Gustafsson 1981) which show that these clusters are more metal-deficient than previously believed.

The conclusion would be that field stars of intermediate population II have their cluster analogues in the metal-deficient open clusters rather than in the metal-rich globular clusters. Examples of such metal-deficient open clusters are NGC 2243, 2420 and 2506 and Mel 66. According to Janes (1979) these clusters have metal abundances of about [Fe/H] = –0.5. None of them show any red horizontal branch.

It is a pleasure for the present writers to express their gratitude to Dr. P.E. Nissen for valuable comments on the manuscript.

REFERENCES

Abt, H.A. 1958, *Ap. J.*, **127**, 658.
Ardeberg, A. and Gustafsson, B. 1981, in preparation.
Bartkevičius, A. 1980, *Vilnius Astron. Obs. Bull.*, 51.
Bell, R.A. and Gustafsson, B. 1981, in preparation.
Cayrel de Strobel, G., Bentolila, C., Hauck, B., and Curchod, A. 1980, *Astr. and Ap. Suppl.*, 41, 405.
Crawford, D.L. 1966, in *IUA Symp. No. 24, Spectral Classific tion and Multicolour Photometry*, eds. K. Lodén, L.O. Lod and U. Sinnerstad (London and New York: Academic Pres p. 170.
Crawford, D.L. 1975*a* *Pub. A.S.P.*, 87, 481.
Crawford, D.L. 1975*b*, *A.J.*, 80, 955.
Crawford, D.L. 1978, *A.J.*, 83, 48.
Crawford, D.L. and Barnes, J.V. 1970, *A.J.*, 75, 978.
Crawford, D.L. and Mandwewala, N. 1976, *Pub. A.S.P.*, 88, 91
Eggen, O.J. 1976, *Pub. A.S.P.* 88, 732.
Eggen, O.J. 1978, *Ap. J.*, **221**, 881.
Grønbech, B., Olsen, E.H., and Strömgren, B. 1976, *Astr. a Ap. Suppl.*, **26**, 155.
Greenstein, J.L. and Keenan, P.C. 1958, *Ap. J.*, **127**, 172.
Gustafsson, B. and Ardeberg, A. 1978, in *Astronomical Pape dedicated to Bengt Strömgren*, eds. A. Reiz and T. Anders (Denmark: Copenhagen University Observatory) p. 145.
Gustafsson, B. and Bell, R.A. 1979, *Astr. and Ap.*, 74, 313
Gustafsson, B., Kjaergaard, P., and Andersen, S. 1974, *Astr. a Ap.*, 34, 99.
Janes, K.A. 1979, *Ap. J. Suppl.*, 39, 135.
Johnson, H.L. and Morgan, W.W. 1953, *Ap. J.*, **117**, 313.
Keenan, P.C. and Keller, G. 1953, *Ap. J.*, **117**, 241.
Keenan, P.C. and Pitts, R.E. 1980, *Ap. J. Suppl.*, **42**, 541.
Keith, D.W. and Butler, D. 1980, *A.J.*, 85, 36.
Landi, J., Jaschek, M., and Jaschek, C. 1977, *An Atlas of Grati Stellar Spectra at Intermediate Dispersion* (Argentin Universidad Nacional de Córdoba).
Morgan, W.W., Harris, D.L., and Johnson, H.L. 1953, *Ap.* **118**, 92.
Morgan, W.W. and Keenan, P.C. 1973, *Ann. Rev. Astr. and A* 11, 29.
Morgan, W.W., Keenan, P.C., and Kellman, S. 1943, *An Atlas Stellar Spectra with an Outline of Spectral Classificati Astrophysical Monographs* (Chicago: The University Chicago Press).
Morgan, W.W. and Roman, N. 1950, *Ap. J.*, **112**, 362.
Nissen, P.E. 1981, *Astr. and Ap.*, in press.
Nissen, P.E. and Gustafsson, B. 1978, in *Astronomical Pap dedicated to Bengt Strömgren*, eds. A. Reiz and T. Anders (Denmark: Copenhagen University Observatory), p. 43.
Pilachowski, C.A., Canterna, R., and Wallerstein, G. 1980, *Ap. (Letters)*, **235**, L21.
Renzini, A. 1977 in *Advanced Stages in Stellar Evolution*, eds. Bouvier and A. Maeder (Sauverny, Switzerland: Gene Observatory), p. 149.
Strömgren, B. 1963*a*, *Quart. J.R.A.S.*, 4, 8.
Strömgren, B. 1963*b*, *Basic Astronomical Data*, ed. K. Strand, (Chicago: University of Chicago Press), p. 123.
Strömgren, B. 1966, *Ann. Rev. Astr. and Ap.*, 4, 433.

DISCUSSION

Torres-Peimbert: Se observan muy pocos objetos de población II extrema. ¿Es esto consistente con otros datos?

Ardeberg: Vista la magnitud límite de la presente búsqueda la tasa de ocurrencia de objetos de población II extrema es consistente con otras investigaciones.

Arne Ardeberg: European Southern Observatory, Casilla 27-D, La Silla, La Serena, Chile.
H. Lindgren: Lund Observatory, Svanegatan 9, S-22224 Lund, Suecia.