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CCD *BVRI* PHOTOMETRY OF A REGION IN BAADE'S WINDOW

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RESUMEN

Se obtuvieron imágenes CCD con los filtros *BVRI* de una región en la Ventana de Baade en la cual se ha realizado un estudio infrarrojo muy completo (Ruelas-Mayorga & Teague 1992a). Nuestra idea es la de estudiar las propiedades de estas estrellas en un intervalo de longitudes de onda más corto y de compararlas con el estudio IR mencionado anteriormente. Se presentan algunos resultados preliminares de este estudio en forma de diagramas magnitud-color y color-color. En estos diagramas se nota que existen por lo menos dos secuencias de estrellas; una que es brillante y se extiende hacia el azul (disco) y otra más débil y roja (bulbo). El ancho de las secuencias en los diagramas de dos colores varía como función del color y esto quizás indique un cambio y/o un ensanchamiento de la distribución de metalicidad en estas estrellas.

ABSTRACT

We obtained CCD *BVRI* frames of a region in Baade's Window for which we have previously conducted a very extensive infrared study (Ruelas-Mayorga & Teague 1992a) with the idea of studying the properties of these stars in the shorter wavelength interval and of comparing with the IR study mentioned above. We present preliminary results of this study in the form of magnitude-colour and colour-colour diagrams. We note that there are at least two different sequences of stars; one that is bright and extends towards the blue (disc) and another one fainter and redder (bulge). The width of the sequences on the colour-colour diagrams varies as a function of colour and may denote a change and/or a spread of metallicity.

Key words: **HERTZSPRUNG-RUSSELL DIAGRAM — STARS: LATE TYPE — TECHNIQUES: PHOTOMETRIC**

1. INTRODUCTION

Baade's Window (BW) is a low obscuration region through which it is possible to observe stars located far way from the Sun; the bulk of these stars is at a distance smaller than 2 kpc from the galactic centre; this fact as compelled many astronomers to think of this stellar population as belonging entirely to the galactic bulge. Iany studies of this stellar population may be found in the literature; there are, however, several which will be ummarised in this section due to their importance regarding the results presented here. Arp (1965) performed 3 and V photographic photometry of stars in BW, and from his V vs. $B - V$ diagrams for more than 1300 tars, he finds that the giant branch (GB) defined by stars in this region is considerably broader than giant ranches in globular clusters; this indicates an inhomogeneity of the age and/or the metallicity of the stars in he bulge. The metallicity values he finds are similar to those for the 47 Tuc GB and higher; he concludes that he stellar population of the bulge is composed by old, low mass, high metallicity stars. van den Bergh (1971, 972) and van den Bergh & Herbst (1974) study, also by means of photographic photometry, the region at BW nd a low obscuration region at $l \sim 0.0°$, $b \sim -8.0°$. Arp's (1965) results are corroborated in these papers;

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however, with the benefit of deeper plates, these authors are able to establish a range in metallicity from th value for the GB of M3 to that of the solar neighbourhood. They also find a distinctive metallicity stratificatio for the giants in the galactic bulge.

Frogel & Whitford (1987) published a very extensive infrared (IR) study of the stars in BW. When compare to the solar neighbourhood M giants, they find that:

i) At the same spectral type, bulge giants have bluer JHK colours but stronger CO indices. ii) The nearl dispersionless $J-H$, $H-K$ relation for the bulge giants lies on the opposite side of the field giant mean relatio from that for globular cluster giants. iii) Bulge giants are up to 2 magnitudes fainter than field giants of th same spectral type, and their luminosity function drops precipitously for M_{bol} brighter than -4.2. They als conclude that the metallicity of these stars is well in excess of that for solar neighbourhood M giants.

Rich (1988) presents an impressive abundance study of 88 K-giants in BW. He concludes that the stella population of the galactic bulge is completely different from the local disc, globular clusters and other resolve populations that have been studied, as it has a wide range of abundances and contains the most metal-ric stars known. He finds a mean [Fe/H] for BW of 0.0 ± 0.4. Terndrup (1988) presents CCD BVI photometr of 4 fields in the galactic bulge. He concludes that all the colour-magnitude diagrams show an old, metal-ric population with a significant dispersion in metallicity. The metallicity of the bulge decreases by about 0.5 de from $b = -3.9°$ to $b = -10°$. Optical colours are significantly bluer than expected from the metallicity values.

Ruelas-Mayorga & Teague (1992a, 1992b, 1993) present IR studies of stars in BW and other clear regior around the galactic centre. They find that:

i) The stellar population in BW may be consistently separated into two sequences; a brighter (disc) and fainter (bulge). ii) These sequences may also be associated with higher (brighter) and lower (fainter) metallicit values. iii) The slope of the Luminosity Function of the fainter stars is similar to that for globular cluster which suggests that this stellar population may have the same mass, age and metallicity characteristics as th stars in globular clusters.

From what precedes we see that the great wealth of studies of the stellar population in the direction of th galactic bulge is not conclusive as to its origin and physical characteristics. We therefore propose to conduct photometric study of this stellar population in the four filters $BVRI$ both at the brighter as well as the faint magnitude ranges in order to try to settle some of the problems and contradictions encountered.

In § 2 we present our observations; § 3 consists of a brief discussion of the data while § 4 outlines ou conclusions.

2. OBSERVATIONS

The observations were obtained at the Observatorio Astronómico Nacional on the nights of 1991 April and 28. The direct image CCD camera was used attached to the 2.1-m telescope. The camera consists of CCD chip of the Thompson type with a size of 576 × 384 pixels; when projected over the sky, this chip cove an area of approximately 3 × 2 arcmin. Standard observational techniques were followed. No dark frames we obtained because the integration times of our observations were short and no appreciable background coun would accumulate during these time intervals.

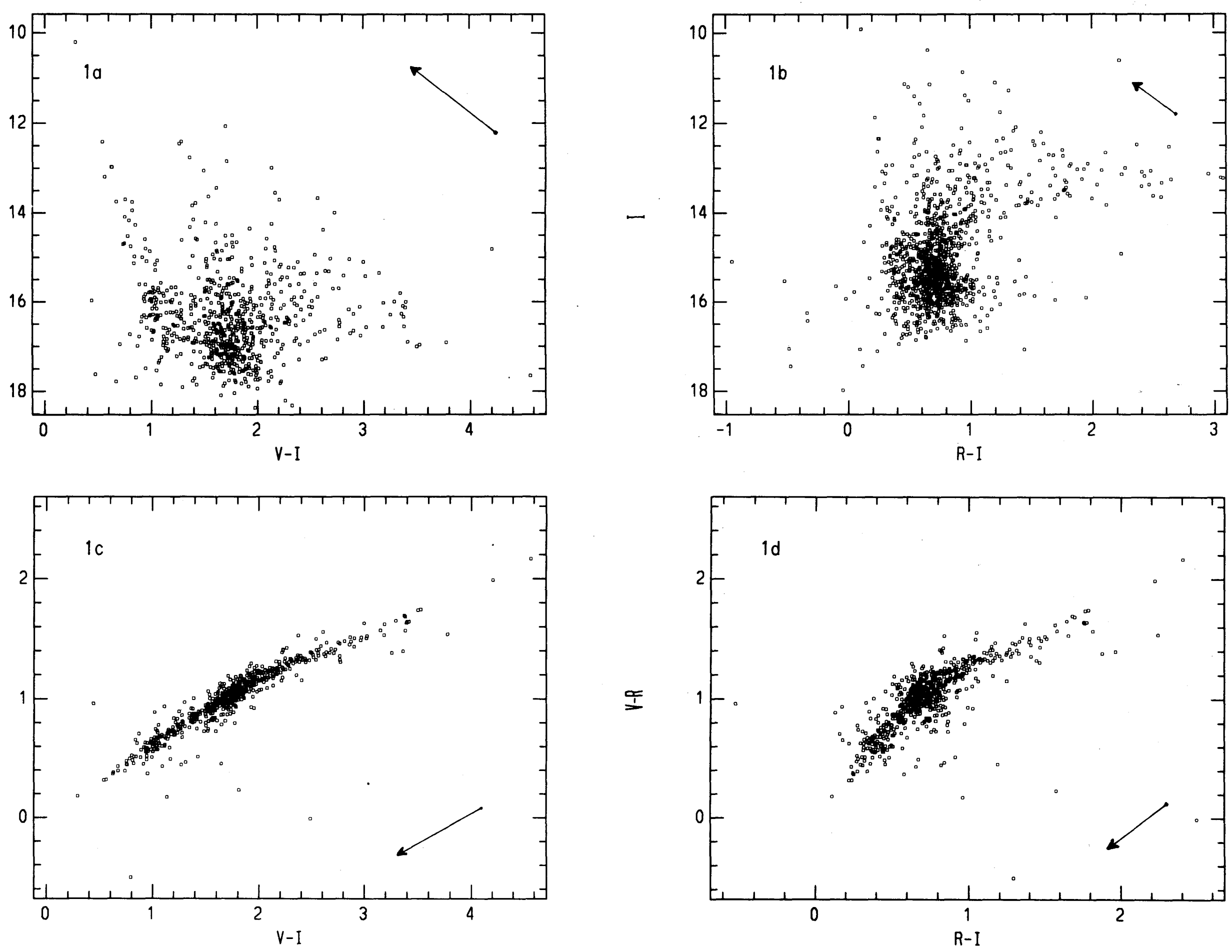
The observations presented in this paper consist of $BVRI$ frames for ten regions ($\sim$ 60 arcmin^2) located BW. They coincide with the IR-scanned strip studied by Ruelas-Mayorga & Teague (1992a) whose coordinat at the centre are RA(1950)=18h 02m 54s and DEC(1950)= $-29°\ 51'\ 56''$. The integration times for each filt were as follows: 50 seconds for the R and I filters and 100 seconds for the B and V filters. Calibration the observations was achieved by comparison with CCD fields in the same BW region observed by Walker Mack (1986) within which there is a photoelectric sequence. The reduction of the data was done followi standard techniques and using the package DAOPHOT (Stetson 1987). The sample of stars used for this pap is complete down to the following magnitudes: 17.5 for B, 17.0 for V, 16.3 for R and 15.7 for I.

3. DISCUSSION

A total number of stars of the order 300–400 is found in each frame, depending on the filter used, producin a grand total of $\sim$ 3000 for the ten fields studied.

Colour-magnitude diagrams as well as colour-colour diagrams were produced for all the possib combinations of the $BVRI$ filters. Here we shall present only the V vs. $V-I$, the I vs. $R-I$, the $V-R$ v $V-I$ and $V-R$ vs. $R-I$ diagrams (see Figure 1).

The V vs. $V - I$ diagram (Figure 1a) is presented first because of the large number of stars which are ·en on it and also because it is possible to compare it to a similar diagram published in a paper by Terndrup .988) in which he also studies the stellar population in the direction of the galactic bulge. When comparing ıis diagram with Terndrup's we see that ours does not extend to magnitudes as deep as his diagram does, ɔwever, above $V = 18$ both diagrams are very similar. It is interesting to note that our diagram extends to $- I \sim 3.9$ whereas his reaches only up to $V - I \sim 2.9$. We believe that due to the larger diameter of the ·lescope he used, the red stars which we find here would have been saturated in his observations, that being ıe reason why he does not plot them on his diagram. The most interesting fact noted on our diagram is that at :ight magnitudes there appears to be a number of distinct stellar sequences. There is a branch which extends om $V \sim 17$ and $V - I \sim 0.9$ to $V \sim 10$ and $V - I \sim 0.3$ which both Terndrup and we have identified with ıe disc contribution. We differ in that he identifies this branch with foreground stars whereas we claim that, /en though there may be a number of foreground objects observed in these fields, our model of the Galaxy Ɩuelas-Mayorga 1991a, b) does not allow for a large number of foreground stars, compelling us to conclude ıat there is a disc contribution to this stellar population which is located near the galactic centre. On the red de of this diagram, Terndrup (1988) also finds a branch which extends towards brighter and redder sections of ıe figure. We also find this branch; however, it seems to us that it separates into at least four distinct branches. /e find a wide branch that ascends almost vertically at a $V - I \sim 1.5$ which, after correcting for reddening,



ig. 1. a) V vs. $V - I$ diagram. Note the bright blue band extending upwards (disc ?) and other branches. b) vs $R - I$ diagram. Note the clump of stars at $I \sim 16$, the bright vertical branches and the broad transversal ranch extending up to $R - I \sim 3.0$. c) $V - R$ vs. $V - I$ diagram. Note the slight kink at $V - R \sim 1.0$. d) $' - R$ vs. $R - I$ diagram. Note the kink at $V - R \sim 1.0$. In figures c) and d) the sequences appear much roader at their blue ends. As of yet, no interpretation has been found for the kinks in figures c) and d). In all gures the arrow represents the dereddening vector.

corresponds to stars of spectral type F8. There is another very thin branch which also ascends almost verticall up to $V \sim 13$ at a $V - I \sim 2.05$ which would correspond to stars of spectral type K1. The third branch rur up to $V \sim 16$ and $V - I \sim 3.0$ and finally another very red branch with a magnitude $V \sim 16$–17 starting fro a $V - I \sim 1.8$ and ending at $V - I \sim 3.9$.

Figure 1b shows the I vs. $R - I$ diagram. Here we can see that at bright magnitudes there is also a gre deal of structure: at least two vertical branches and a very broad transversal branch are observed. A clump stars is observed at $I \sim 15.5$ with a $R - I \sim 0.7$. It is interesting to note that to the best of our knowledg these are the first observations taken with the R filter for this stellar population.

Figure 1c depicts the two-colour diagram $V - R$ vs. $V - I$. This graph contains a sequence of stars th extends from $V - R \sim 0.2$ and $V - I \sim 0.3$ to $V - R \sim 2.2$ and $V - I \sim 4.5$. The average width of th sequence is ~ 0.25 magnitudes with an average standard deviation of ~ 0.07. There are two very conspicuo stellar concentrations at $V - R \sim 1.0$ and $V - I \sim 1.75$ and at $V - R \sim 0.6$ and $V - I \sim 1.0$ respectively. It interesting to note that the average separation between these two concentrations lies exactly on the reddenir vector at a $\Delta(V - R) \sim 0.4$ and $\Delta(V - I) \sim 0.75$ which correspond pretty well to the colour excesses of t galactic bulge ($E(V - R) \sim 0.36$ and $E(V - I) \sim 0.73$).

Finally on Figure 1d we observe the $V - R$ vs. $V - I$ two-colour diagram. Here it is noted that there a two important concentrations of stars and that the average width of the diagram seems to vary, being mu wider at the blue end than at the red end. For the two colour-colour diagrams which are presented here the is a very noticeable kink just to the red of the more important concentration of stars. We do not as yet ha an interpretation for this feature.

4. CONCLUSIONS

From these preliminary results we conclude the following:

i) There is a substantial number of disc stars in the low absorption windows through which the galact bulge is usually studied. Allowance for their presence must always be made.

ii) In agreement with the results found in the bright IR ($K \leq +9$) (see Ruelas-Mayorga & Teague 1993 in the bright visual magnitude range ($V \leq +18$) bulge sources must have on the average red colours ($V - I$ $+2.0$) which, after dereddening [$(V - I)_0 \geq +1.27$] imply spectral types later than G8 III.

iii) We note several branches of stars in the diagrams which may be possibly identified with stars in t foreground (blue branch) and with stars in the region surrounding the galactic centre.

iv) For the stars around the galactic centre we find, in agreement with other authors' results, that there a range of metallicity which goes from high to low metallicity. We propose that the high metallicity stars m be interpreted as disc produced, whereas the low metallicity ones belong to what we like to call the 'true bulg population.

v) Kinematical studies would be desirable to try to separate by means of the velocity dispersion those sta that belong to the disc and to the bulge. Unfortunately there are some indications that a disc located close the galactic centre would have a high value for its velocity dispersion (Freeman 1987). Separation by magnitu (fainter and brighter) of samples of BW-stars studied by Mould (1983) and by Sharples, Walker, & Cropp (1990) indicate a substantial difference in the value of their velocity dispersion in the sense expected by u That is, faint stars (true bulge) have higher velocity dispersion than brighter stars (disc).

vi) Deeper CCD frames would allow the identification of main-sequence stars, which presumably belo in their entirety to the 'true bulge' (except for a few foreground objects), and also permit identification of t turn-off point which would yield, by means of model fitting, an age for this stellar population.

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DISCUSSION

)ufour: Have you used two-color diagrams in your analysis, particularly to reject spurious data?

Luelas-Mayorga: We have produced a number of two-colour diagrams from which spurious data may easily e identified. We are, however, still analysing the data. No definite results have been obtained from these iagrams.

Carrasco: What transformation equation did you use to get your R_J and I_J magnitudes? To my knowledge he filters available at San Pedro Mártir are R and I in the Cousins system. Perhaps your "kinks" are the on-linearities of the photometric transformations that Newell has reported (see also recent papers by Bessell).

Luelas-Mayorga: The transformations used were those appropriate for Johnson filters. We do need to check ow the results would change if Kron-Cousins' instead of Johnson's transformations are used.

,ópez Cruz: Why didn't you use twilight flat fields? What is the angular size of the Baade's Window? I think ou should be careful when you refer to structures and gaps in your CMD because you are limited by the way ou have sampled the area. Perhaps if you go deeper all of those structures will disappear?

Luelas-Mayorga: Twilight flats were not used simply because it proved easier observing screen flats and ecause we had no information as to the gradient seen on them. Baade's Window is large enough to accommodate t least 50 2 × 3 arcmin frames side by side. As for as the structures seen on the diagrams, I agree they may lisappear as deeper data are obtained; however, if they do persist they must mean something and it is interesting o note their presence.

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