EVIDENCE FOR THE GALACTIC BAR FROM THE TWO COLOR PHOTOMETRY OF THE BULGE RED CLUMP STARS

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1. Introduction

The Optical Gravitational Lensing Experiment (OGLE, Udalski et al. 1994a; Paczyński et al. 1994b – these proceedings; and references therein) is an extensive photometric search for the rare cases of gravitational microlensing of Galactic bulge stars by foreground objects. It provides a huge data base (Szymański & Udalski 1993), from which color-magnitude diagrams have been compiled (Udalski et al. 1993, 1994b). Here we discuss the use a of well-defined population of bulge red clump stars to investigate the presence of the bar in our Galaxy. The results of our earlier studies are described by Stanek et al. (1994).

There are now a number of photometric and dynamical indications that the Galaxy is barred (de Vaucouleurs 1964; Blitz & Spergel 1991; Binney et al. 1991; Whitelock & Catchpole 1992; Weinberg 1992; for a review see Blitz 1993). The bar is clearly present in the COBE DIRBE data (Weiland

L. Blitz and P. Teuben (eds.), Unsolved Problems of the Milky Way, 103–109.

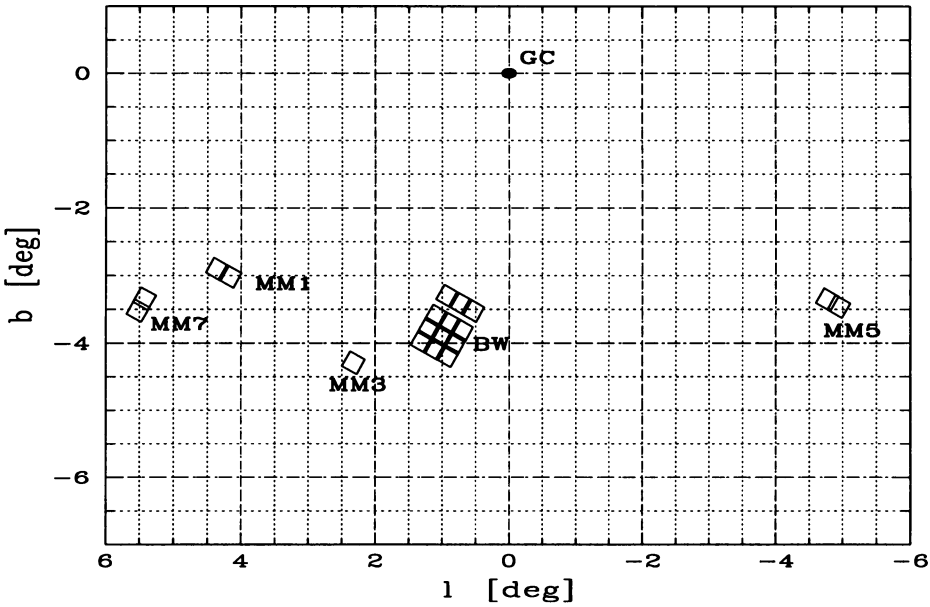

Figure 1. Positions in the Galactic coordinates of 19 fields discussed in this report, for which the $V - I$ color-magnitude diagrams were obtained by the OGLE experiment (Udalski et al. 1993, 1994b).

et al. 1994), which was used by Dwek et al. (1994; also this proceedings) to constrain a number of analytical bar models existing in the literature.

2. The Data

Udalski et al. (1993, 1994b) present color-magnitude diagrams (CMDs) of 19 fields in the direction of the Galactic bulge, which cover nearly 1.5 square degrees and contain about 8×10^5 stars. Fig.1 shows the positions of all 19 fields in galactic coordinates. As an example, the CMD for one of the positive galactic longitude fields (MM7-A) is shown in Fig.2, with main populations of stars schematically illustrated. The part of the diagram dominated by the disk stars was recently analyzed by Paczyński et al. (1994a). Here we use a well-defined population of bulge red clump stars to investigate the presence of the bar in our Galaxy. The results of our earlier studies are presented by Stanek et al. (1994).

To analyze the distribution of bulge red clump stars in a quantitative manner, we define the extinction-insensitive V_{V-I} parameter

$$V_{V-I} \equiv V - 2.6\,(V - I), \tag{1}$$

where we use reddening law $E_{V-I} = A_V/2.6$. The parameter V_{V-I} has been defined so that if A_V/E_{V-I} is independent of location then for any

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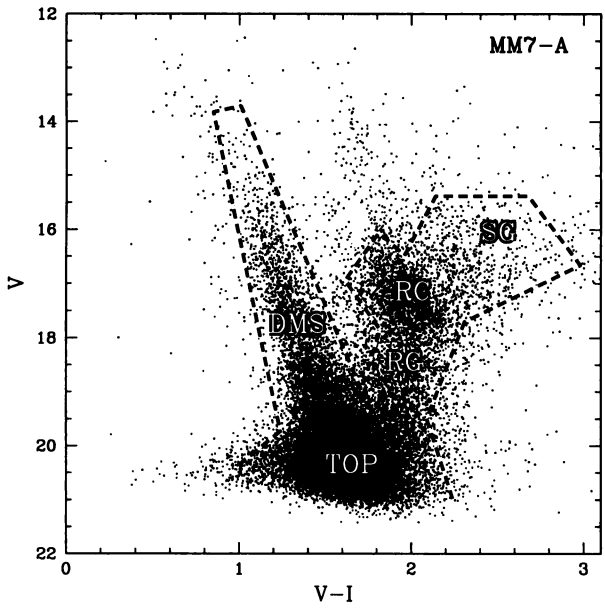

Figure 2. The $V - I$ color-magnitude diagram for stars in the MM7-A field of the OGLE experiment (Udalski et al. 1993). Schematically shown are main populations of stars: TOP – Turn-Off Point, RG – Red Giants, RC – Red Clump, SG – Super-Giants and DMS – Disk Main-Sequence.

particular star its value is not affected by the unknown extinction (see Stanek et al. 1994). The part of the CMD dominated by bulge red clump stars is shown, for six out of all 19 observed fields, in Fig.3. The fields were ordered from top-left to bottom-right by decreasing galactic longitude l. Also shown are two lines corresponding to the V_{V-I} values equal to 11.5 and 13.0. It is clearly visible that the red clump stars from fields with larger l group near to the $V_{V-I} = 11.5$ line, while red clump stars from the fields with smaller (negative) l have, on average, larger values of this parameter.

To quantify the effect observed in Fig.3, for all 19 fields we select the region of the CMD clearly dominated by the bulge red clump stars:

$$1.4 < V - I \;\; ; \;\; 10.5 < V_{V-I} < 14.0 \qquad (2)$$

For every field all stars that satisfied the inequalities (2) were counted in bins of $\Delta V_{V-I} = 0.05$. The result appears in Fig.4, where we show the number of stars as a function of V_{V-I} for the same six fields as in Fig.3. The distributions shown in Fig.4 are similar in shape, with red clump stars forming a pronounced peak. There is however a clear shift between the distributions, in the sense that stars from fields with bigger value of l have on average smaller values of V_{V-I} parameter. To quantify this shift, for every

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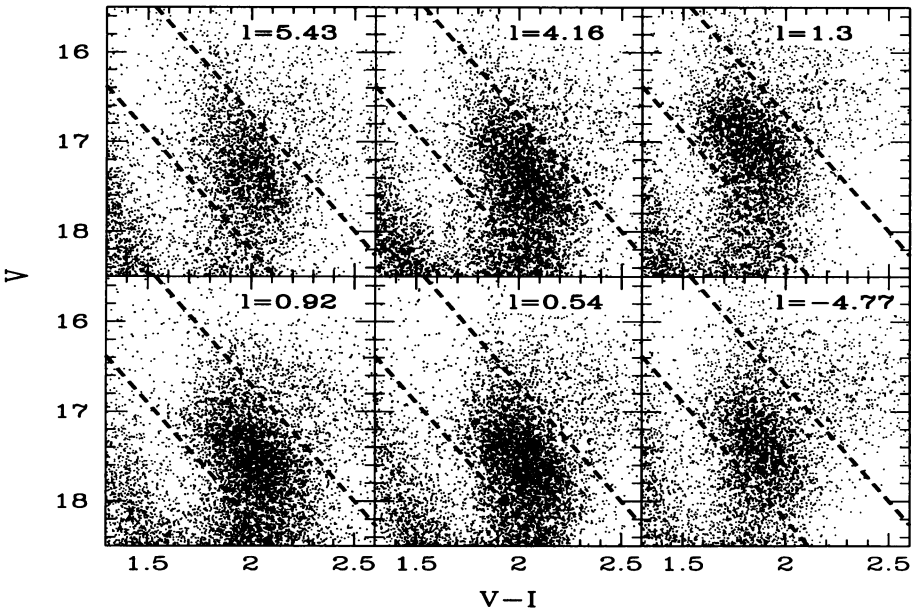

Figure 3. Region of the $V - I$ color-magnitude diagrams dominated by bulge red clump stars for six out of all 19 observed fields, ordered from top-left to bottom-right by decreasing galactic longitude l. The two straight lines correspond to the value of extinction-insensitive parameter V_{V-I} equal to 11.5 and 13.0 (Eq.1).

field we found the mode of the V_{V-I} distribution (see Stanek et al. 1994). The resulting plot of the mode as a function of galactic longitude l for every field is shown in Fig.5. There is a clear anti-correlation between the V_{V-I} value of the mode and the Galactic longitude l for a given field that corresponds to decrease of V_{V-I} value of $\sim 0.04\ mag/$ deg.

3. Discussion

In the previous section we have shown that the distributions of bulge red clump stars, observed in various fields, as a function of extinction-adjusted apparent magnitude are similar in shape but are systematically shifted. This is likely due to the difference in the distance to the bulge red clump stars in various fields, an indication that the bulge is not axially symmetric. If we assume that the peaks of the V_{V-I} distributions correspond to the stars lying at the major axis of the bar, we can obtain the angle of inclination of the bar to the line of sight, $\theta \approx 45$ deg. For a very thin bar such an inclination angle corresponds directly to the true inclination angle, but if the bar is thick then the true inclination angle is smaller (Stanek et al. 1994). It is possible to use the observed luminosity function of red clump

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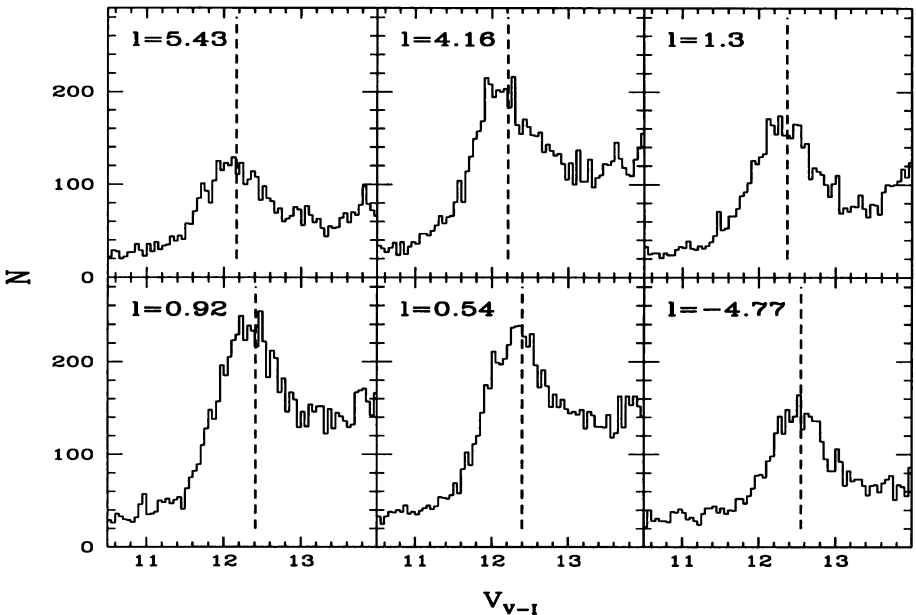

Figure 4. Plot of the V_{V-I} distributions for the same six fields as in Fig.4. With the vertical dashed lines we mark the position of the mode of the distributions.

stars to put constraints on various models of the Galactic bar. This have the advantage over the studies using surface brightness measurements (Dwek et al. 1994) that the red clump stars provide us with information about the depth of the bar along the line of sight. Such information was recently used by Stanek (1994) in his study of the magnitude offset between gravitationally lensed stars and observed stars. The preliminary results from the modelling of the Galactic bar by fitting the observed red clump luminosity function (Stanek et al., in preparation) indicates that the inclination of the Galactic bar to the line of sight is about ~ 20 deg, but it is too early to say how robust this result is.

The presence of the bar in the Galaxy seems to be firmly established by various authors and methods, but there are still considerable differences as to details of the bar structure or angle of inclination to the line of sight. We have shown that the red clump stars can be very useful for investigating the Galactic bar, being both numerous and relatively bright. We are now extending the work presented here, by incorporating more information provided by the red clump region of CMDs, to test a variety of Galactic bar models (Stanek et al., in preparation).

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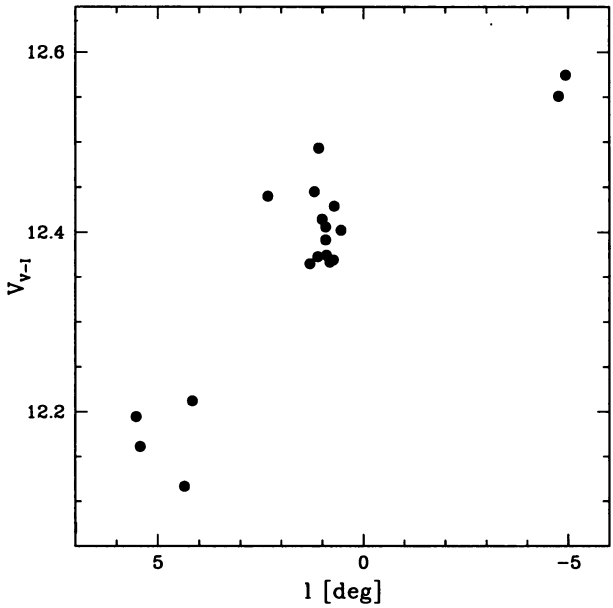

Figure 5. Correlation between the mode of the V_{V-I} distribution and the Galactic longitude l for all observed fields.

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References

Binney, J., Gerhard, O. E., Stark, A. A., Bally, J., & Uchida, K. I., 1991, MNRAS, 252, 210
Blitz, L., & Spergel, D. N., 1991, ApJ, 379, 631
Blitz, L. 1993, in "Back to the Galaxy", AIP Conference Proceedings 278, eds. S. S. Holt & F. Verter, (New York: AIP Conference Proceedings), p.98
de Vaucouleurs, G. 1964, in IAU Symp. No. 20, eds. F. J. Kerr and A. W. Rodgers (Australian Acad. Sci.: Canberra), p.195
Dwek, E., et al. 1994, ApJ, submitted (also these Proceedings)
Paczyński, B., Stanek, K. Z., Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., & Mateo, M., 1994a, AJ, 107, 2060
Paczyński, B., et al. 1994b, these Proceedings
Stanek, K. Z., Mateo, M., Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., 1994, ApJ, 429, L73
Stanek, K. Z., 1994, ApJ, submitted
Szymański, M., & Udalski, A. 1993, Acta Astron., 43, 91
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., & Mateo, M. 1993, Acta Astron., 43, 69
Udalski, A., Szymański, M., Stanek, K. Z., Kałużny, J., Kubiak, M., Mateo, M., Krzemiński, W., Paczyński, B., & Venkat, R. 1994a, Acta Astron., 44, 165
Udalski, A., et al. 1994b, Acta Astronomica, submitted
Weiland, J. L., et al., 1994, ApJ, 425, L81

Weinberg, M. D., 1992, ApJ, 384, 81
Whitelock, P., & Catchpole, R., 1992, in The Center, Bulge, and Disk of the Milky Way, ed. L. Blitz, (Dordrecht: Kluwer Academic), p. 103

DISCUSSION

I. King: Are your red-clump stars good enough standard candles that they can tell you anything about the extent of the bar/bulge along the line of sight?

Stanek: Without any knowledge about the intrinsic properties of the red clump stars we can roughly say only that the FWHM indicates that the depth of the bar along the line of the sight is $\lesssim$ 4kpc.

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