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Mira variables in the Galactic Bulge

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Abstract. The 222 000 I-band light curves of variable stars detected by the OGLE–II survey in the direction of the Galactic Bulge have been fitted and have been correlated with the DENIS and 2MASS databases. Results are presented for 2691 objects with I-band semi-amplitude larger than 0.45 magnitude, corresponding to classical Mira variables. The Mira period distribution of 5 fields at similar longitude but spanning latitudes from -1.2 to -5.8 are statistically indistinguishable indicating similar populations with initial masses of 1.5-2 $M_{\odot}$ (corresponding to ages of 1-3 Gyr). A field at similar longitude at $b = -0.05$ from Glass et al. (2001) does show a significantly different period distribution, indicating the presence of a younger population of 2.5-3 $M_{\odot}$ and ages below 1 Gyr. The K-band period-luminosity relation is presented for the whole sample, and for sub-fields. Simulations are carried out to show that the observations are naturally explained using the model of disk and bulge stars of Binney et al. (1997), for a viewing angle (major-axis Bar - axis perpendicular to the line-of-sight to the Galactic Centre) of 43 ± 17 degrees. A comparison is made with similar objects in the Magellanic Clouds, studied in a previous paper. The slope of the PL-relation in the Bulge and the MCs agree within the errorbars. Assuming the zero point does not depend on metallicity, a distance modulus difference of 3.72 between Bulge and LMC is derived. This implies a LMC DM of 18.21 for an assumed distance to the Galactic Centre (GC) of 7.9 kpc, or, assuming a LMC DM of 18.50, a distance to the GC of 9.0 kpc. From the results in Groenewegen (2004) it is found for carbon-rich Miras that the PL-relation implies a relative SMC-LMC DM of 0.38, assuming no metallicity dependence. This is somewhat smaller than the often quoted value near 0.50. Following theoretical work by Wood (1990) a metallicity term of the form $M_{\rm K} \sim \beta \log Z$ is introduced. If a relative SMC-LMC DM of 0.50 is imposed, $\beta = 0.4$ is required, and for that value the distance to the GC becomes 8.6 ± 0.7 kpc (for a LMC DM of 18.50), within the errorbar of the geometric determination of 7.9 ± 0.4 kpc (Eisenhauer et al. 2003). An independent estimate using the absolute calibration of Feast (2004) leads to a distance estimate to the GC of 8.8 ± 0.4 kpc.

Key words. Stars: AGB and post-AGB, Galaxy: bulge, Galaxy: center

1. Introduction

This short paper is a summary of the paper by Groenewegen & Blommaert (2005; GB05) to which we refer for all details. GB05 itself an extension of the work of Groenewegen (2004; hereafter G04), who analysed the OGLE-II data in the direction of the SMC and LMC for Mira variables.

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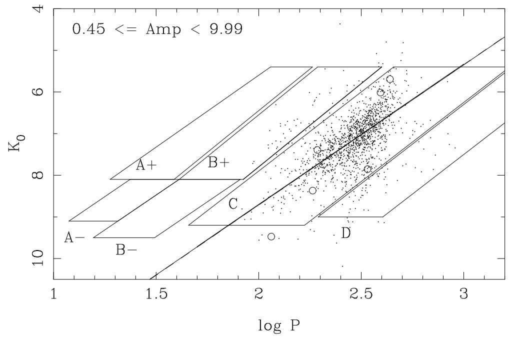

Fig. 1. *K*-band *PL*-relation for periods with an *I*-band amplitude larger than 0.45 mag and $(J-K)_0 < 2.0$. Indicated are Sequences/Boxes "A+, A-, B+, B-, C, D". Box "C" defines the region of the Miras. The line is the *PL*-relation of Eq. 1

2. Results

In GB05 the 222 000 *I*-band lightcurves in the direction of 49 OGLE-II fields presented in Wozniak et al. (2002) have been analysed, by determining up to 3 periods and fitting sine and cosine functions. In the rest of the analysis stars which have at least one period with an *I*-band (semi-) amplitude larger than 0.45 magnitudes, i.e. classical Mira variables. After visual inspection of the lightcurves a sample of 2691 such objects remain. The sample is correlated with the 2MASS and DENIS databases to obtain single-epoch infrared data.

Figure 1 shows the *K*-band Period-Luninosity relation for all periods which have an *I*-band amplitude larger than 0.45 magnitude and $(J-K)_0 < 2.0$. Magnitudes are dereddened using the A_V values that correspond to the respective OGLE field taken from Sumi (2004; and $A_V = 6.0$ for the field 44 that they do not discuss). The cut in $(J-K)$ colour is needed to prevent that the *K*-magnitude is affected by circumstellar extinction, as shown in G04. The *PL*-relation is found to be:

$$m_K = (-3.37 \pm 0.09)\ \log P + (15.44 \pm 0.21) \quad (1)$$

with an rms of 0.42 and is shown in Fig. 1.

Figure 2 shows the period distribution of selected fields with very similar longitudes that cover a range in latitudes (the stars with $(J-K)_0 < 2.0$ are shown as dashed histogram). To add a field even closer to the GC than surveyed by OGLE the data in Glass et al. (2001, 2002) is considered on a field centered on $l = -0.05, b = -0.05$. They present the results of a *K*-band survey of 24×24 arcmin^2 for LPVs down to $K \sim 12.0$. Extinction is taken from Schultheis et al. (1999), multiplied by a factor of 1.35 (see GB05). The conclusion reached in GB05 is that there is a significant population of LPVs with period $\gtrsim$500 days present in the inner field, which remains barely present at latitude $-1.2°$, and is absent for $b \lesssim -1.4°$. To quantify the nature of the Mira Bulge population, synthetic AGB evolutionary models have been calculated, which are described in detail in Appendix C of GB05.

In brief, the synthetic AGB code of Wagenhuber & Groenewegen (1998) was fine-tuned to reproduce the models of Vassiliadis & Wood (1993) and then extended to more initial masses and including mass loss on the RGB. For several initial masses the fundamental mode period distribution was calculated for stars inside the observed instability strip and when the mass loss was below a critical value to simulate the fact that they should be optically visible. From the comparison of the observed period distribution for fields more than 1.2° away from the galactic centre with the theoretical ones, we deduce that the periods can be explained with a population of stars with Main Sequence masses in the range of 1.5 to 2.0 $M_\odot$. A possible extension to smaller masses is possible, but not necessary to explain the periods below 200 days. closer to the centre we need initial masses in the range 2.5 - 3 $M_\odot$. The presence of more massive stars in the inner field at $b = -0.05°$ cannot be excluded, as it turns out that for more massive stars the optically visible Mira phase is essentially absent. We do not see a variation in the period distributions for the higher latitude fields (beyond 1° latitude) and can consider this as a homogeneous "bulge" population, which according to the Vassiliadis & Wood (1993) model has ages in the range of 1 to about 3 Gyr. A more extensive discussion can be found in GB05.

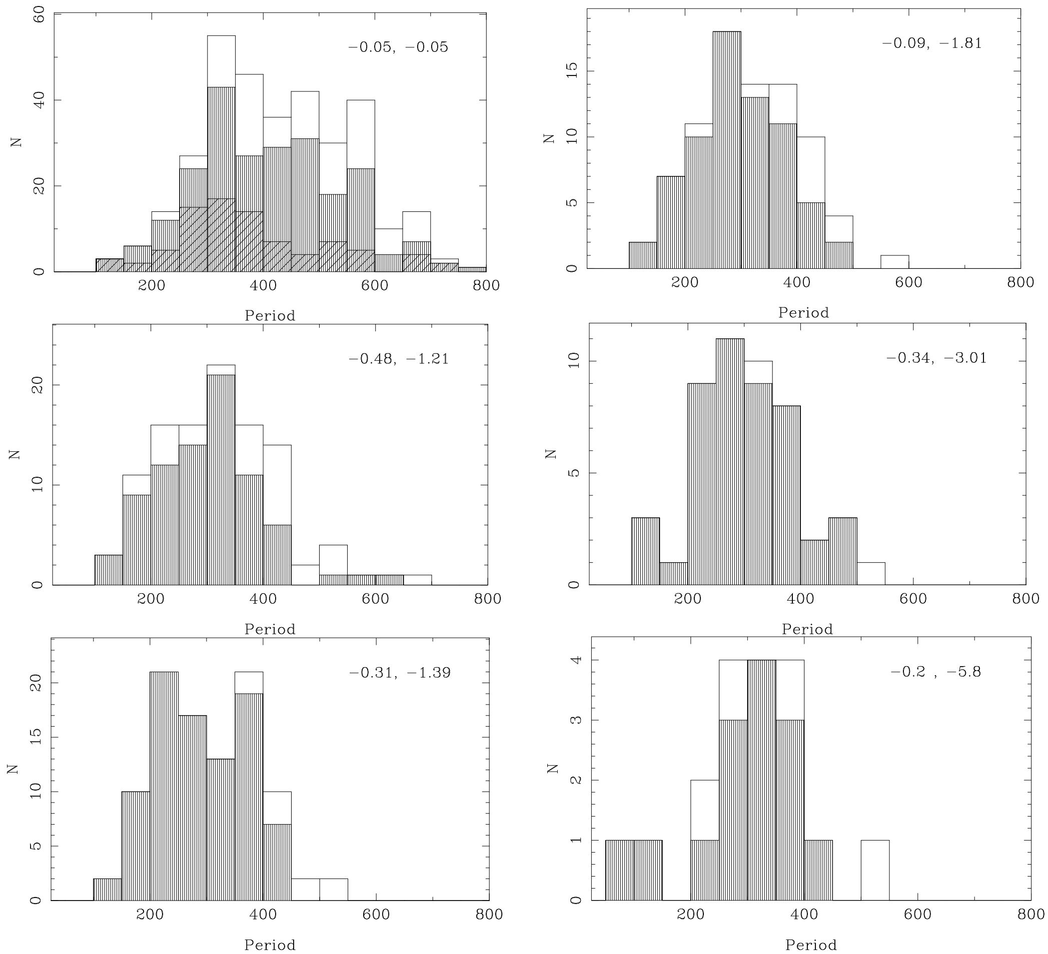

Fig. 2. Mira period distribution for 6 fields with similar longitudes but a range in latitudes (as indicated in the top right corner). For the field at $b \sim -5.8°$, OGLE-II fields 6 and 7 have been combined. For the shaded histograms only stars with $(J-K)_0 < 2.0$ have been included. The field at $(-0.05, -0.05)$ is based on Glass et al. (2001), see main text for details. The histogram with slanted hatching is for the reddening by Schultheis et al. (1999) for stars in this field, the shaded histogram for the adopted reddening which is 1.35 times larger.

3. The distance to the Galactic Centre

Zero points for the K-band PL-relation have been derived in two ways. First, a direct fit to all stars resulting in (15.44 ± 0.21, Eq. 1), and secondly, determining ZPs per (sub)-field, and fitting this as a function of l, resulting in (15.484 ± 0.019). Applying the small bias corrections discussed in GB05 and averaging over the two estimates, the adopted K-band PL-relation for Miras at the GC is:

$$m_K = -3.37 \log P + (15.47 \pm 0.03) \qquad (2)$$

The derived PL-relation can be compared to the one derived for 83 O-rich LPVs in the LMC derived in G04: $m_K = (-3.52 \pm 0.16) \log P + (19.56 \pm 0.38)$, with an rms of 0.26. Since the slopes are not exactly the same, the magnitudes are compared at the approximate mean period of $\log P = 2.45$. The difference in magnitude is 3.72. Adopting the LMC based slope of −3.52 for the GB Miras, and refitting the ZP, the bias corrected ZP would become 15.85, resulting in a GB-LMC DM difference of 3.71, essentially the same value. If the distance to the GC is assumed to be 7.94 kpc (Eisenhauer et al. 2003; in a more recent work this was even lowered to 7.62 ± 0.32 kpc, Eisenhauer et al., 2005), then the LMC would be at a DM = 18.21, or if the DM to the LMC is assumed to be 18.50, then the GC would be at 9.0 kpc. A similar result was found by GWCF who derived a distance to the GC of 8.9 ± 0.7 kpc, assuming 18.55 for the LMC DM and $\phi = 45°$. The analysis so far has assumed no metallicity dependence of the Mira *PL*-relation. Wood (1990) present linear non-adiabatic pulsation calculations that suggest a dependence of the form $\log P \sim 0.46 \log Z + 1.59 \log L$, but he notes that in the *K*-band the dependence is expected to be weaker and following the example he presents one infers a dependence of $0.25 \log Z$ in the *K*-band. In G04 *K*-band *PL*-relations were derived for carbon-miras in the SMC and LMC. At a characteristic period of $\log P = 2.45$ one infers a relative difference in DM of 0.38, which is smaller than the commonly quoted value of near 0.50 (0.48-0.53 ± 0.11, FO cepheids [Bono et al. 2002], 0.46-0.51 ± 0.15, FU cepheids [Groenewegen 2000], 0.44 ± 0.05, TRGB [Cioni et al. 2000]). This may hint at a metallicity dependence of the Mira *K*-band *PL*-relation. To test this hypothesis, a correction to the *K*-magnitude of $+\beta \log Z$ will be assumed (for both O- and C-rich LPVs), and the Bulge, LMC, and SMC will be assumed to have solar, solar/2 and solar/4 metallicity, respectively. For a value $\beta = 0.25$ the relative SMC-LMC DM based on the C-Miras is increased from 0.38 to 0.46, while the relative DM LMC-GC is increased from 3.72 to 3.80. If the relative SMC-LMC DM is fixed at 0.50, then $\beta = 0.40$ is required, and the relative DM LMC-GC becomes 3.84 for that value. For a LMC DM of 18.50, the distance to the GC then becomes 8.6 kpc. We assign an error of 0.7 kpc. Based on this large sample of Mira variables in the direction of the GB the conclusion is that the distance to the GC is between 8.6 and 9.0 (±0.7) kpc, depending on the metallicity dependence of the *K*-band *PL*-relation. Feast (2004) discusses the zeropoint of the Mira *K*-band *PL*-relation, and adopting the slope observed in the LMC (−3.47) derives a zeropoint of 1.00 ± 0.08, averaging over independently derived ZPs from trigonometric parallaxes, OH VLBI expansion parallaxes and Galactic Globular Clusters. Adopting a slope of −3.47 and refitting the ZP of the Bulge sample, the bias corrected value becomes 15.73 ± 0.03, and without metallicity correction (consistent with the assumption above about the metallicities in Bulge, LMC, SMC) leads to a distance to the GC of 8.8 ± 0.4 kpc. This independent distance estimate is in between the values derived using no or a strong metallicity dependent zero point.

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