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Letter to the Editor

The PL relation of galactic carbon LPVs[⋆,⋆⋆,⋆⋆⋆]

The distance modulus to LMC

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Abstract. We present a period-luminosity (PL) diagram of 115 galactic carbon-rich long period variables (LPVs) observed by the HIPPARCOS satellite, in the form of the $(M_{\rm K}, \log P)$ relation. Our plot is compared to the diagram of carbon variables observed in the Large Magellanic Cloud (LMC). Both diagrams are found very similar and three samples are delineated: long period variables close to the PL relation of Feast et al. (1989), short period-overluminous variables and a few underluminous LPVs, respectively Samples 1, 2 and 3. The used data were deduced from expectations of true parallaxes (Knapik et al. 1997) which are statistically free of the Lutz-Kelker effect. The remaining bias due to the non-gaussian distribution of absolute magnitudes is avoided: a non-linear parametric method is applied in Sect. 4 to the analysis of the PL relation for Sample 1 (72 LPVs). We obtain $M_{\rm K} = (-3.99{\pm}0.13)\ \log\ P{+}(2.07{\pm}0.15)$, in good agreement with the slope found for LMC variables by Reid et al. (1995). The LMC distance modulus then derived is $\mu = 18.50 \pm 0.17$. A well-defined upper limit (ul) for long period stars in Sample 1 is found, with similar slopes in both the Galaxy (-4.85) and LMC (-4.72). No correction for metallicity was applied to the results.

Key words: stars: AGB and post-AGB – stars: carbon – stars: fundamental parameters – galaxies: distances

1. Introduction

The period-luminosity (PL) relation for LMC Miras was discovered by Glass & Lloyd Evans (1981) and subsequently refined by Feast (1984) and Feast et al. (1989). According to these authors, the relation is tight with a dispersion of $\pm 0.15\,{\rm mag}$. It is shown in Fig. 1b as the continuous line deduced from LMC Miras observations. A slight revision for carbon Miras was published by Groenewegen & Whitelock (1996). Their zero point of the PL relation relied on the galactic binary member UV Aur. van Leeuwen et al. (1997) made use of the HIPPARCOS data on 16 galactic Miras, including one carbon star (R Lep). They obtained $18.54{\pm}0.18$ for the LMC distance modulus which is close to the 18.5 value frequently adopted from other methods. Our analysis of carbon-rich variables gives 18.50 ± 0.17 (Sect. 4). This result is obtained making use of a sample of 72 galactic carbon LPVs with known periods (Sample 1), out of 115 stars observed in 1989-1993 by HIPPARCOS. They are identified in Fig. 1 as the analogs of the LMC variables concentrated in a clump close to the PL relation of Feast et al. (1989). An upper limit (ul) is also observed which is shown at long periods in both diagrams. Short period stars located markedly above the PL relation (Sample 2: possible overtone pulsators according to the analysis of Wood & Sebo 1996 who identified the LMC clump stars as fundamental pulsators). Underluminous LPVs (Sample 3) are observed in both galaxies. Expectations of true parallaxes generated by Knapik et al. (1997) are used since, contrary to observed parallaxes, they are free of bias induced by errors and non-uniform distribution (which is part of the LK effect). No truncation was operated. It was also shown that the Malmquist bias should be negligible for a sample of bright HIPPARCOS LPVs $(M_{\rm V} \le -1.1)$ provided the estimated true parallaxes are larger than 0.6 mas which is the case here. Making use of the $y{-}{\rm quantity}$ in the parallax space (Sect. 4) yields the same sampling as the non-gaussian absolute magnitudes. The slope and intercept of the PL relation are simultaneously derived making use of a non-linear parametric method. Finally, the LMC distance modulus is deduced and compared to published values.

2. The absolute magnitudes

The near-infrared absolute magnitudes $M_{\rm K}$ are often used in PL-diagrams. Amplitudes smaller than observed in the visible and low corrections for interstellar extinction are also good reasons to make this choice. In addition, it has been argued that the possible effect of metallicity would be smaller on the $(M_{\rm K},\ \log\ P)$

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⋆ This research has made use of the Simbad database operated at CDS, Strasbourg, France.

⋆⋆ Based on data from the ESA HIPPARCOS astrometry satellite

⋆⋆⋆ Table 1 is only available in electronic form at the CDS via anonymous ftp 130.79.128.5

relation than it is on its $(M_{\rm bol},\ \log\ P)$ counterpart (Groenewegen & Whitelock 1996). Here, we restrict ourselves to the former one. The apparent K-magnitudes corrected for interstellar extinction were taken from the data-base of Knapik & Bergeat (1997). The average of maximum and minimum magnitudes can be used for Miras (Feast et al. 1989). For semiregular variables (SRs), mean values were estimated from the available data, the error on the distance modulus prevailing in this latter case. The data on 115 stars to be used hereafter, is given in Table 1 (available only in electronic form at the CDS). The entries are the numbers in Stephenson's catalogue (1989), the period in days, the absolute magnitude $M_{\rm K}$ and y as defined in Sect. 4, the estimated true parallax ϖ in mas and the difference $\Delta\varpi$ with the observed parallax. They were derived from a model of the parallax distribution of HIPPARCOS carbon stars (Knapik et al. 1997). The effect of the space distribution (part of the LK effect) is thus statistically corrected for. Even if the trigonometric parallaxes of the HIPPARCOS catalogue (ESA,1997) are distributed according to a normal gaussian law, this is not the case of the absolute magnitudes or distances (e.g. Smith & Eichhorn 1996). Due to this remaining bias, the y-quantity of Eq. (1) in Sect. 4 is used instead.

3. The $\mathrm{M_K}$ vs. log P diagram

3.1. The three samples

The periods adopted for Miras and SRs were taken from Kholopov et al. 1985 (GCVS) or from ESA (1997, vols. 11-12) for some improved data. The absolute magnitudes of Table 1 are plotted in Fig. 1a against the log of the period in days. The diagram obtained for carbon-rich LMC-stars is shown in Fig. 1b with similar scales. The ordinate is the dereddened apparent magnitude K_0 , taken for carbon variables from Hughes & Wood (1990) and Groenewegen & Whitelock (1996), and 19 stars from Wood & Sebo (1996) (types not specified: shown with quots in Fig. 1). We found strong similarities and no marked differences between both diagrams. A few error bars are shown in Fig. 1a. The usual $(M_{\rm K}, \log {\rm P})$ was kept for easy reference to published LMC data, despite the bias mentioned in Sect. 2. The sampling operated hereafter is found again in the $(y, \log {\rm P})$ diagram as well except possibly for 3 stars conservatively classified in Sample 3, i.e. not used in Sect. 4 analysis). A majority of Fig. 1b variables do concentrate in a clump where $M_{\rm K}$ is increasing with increasing log P close to the PL relation (LMC Sample 1). This strip is widened by a "wave" of brighter stars (LMC Sample 2) in the region $\log\ P \leq 2.4$, while an upper limit (ul) is observed at longer periods. A few underluminous LPVs (LMC Sample 3) are noticed well below the PL relation. The same three samples are observed in Fig. 1a for galactic LPVs. The proportions found (72, 31 and 12 stars respectively) however differ from those in the LMC (190, 32 and 11 respectively). Substantial errors on parallaxes and statistical corrections can result in galactic LPVs scattered from the first sample in the latter two, and conversely of course. Doubtful classification is actually suspected for at least 11 stars located in transition regions: conservatively, they were quoted as 2: or 3: in Table 1. It is worth noting that $\log\ P \geq 2.4$ for our 19 carbon Miras. None of them was found in Sample 2. It is known that, on the average, the carbon Miras have shallower light curves than their oxygen-rich counterparts. Longer periods are required for carbon LPVs to be classified as Miras since amplitudes and periods show a positive correlation. It has been argued that the LMC Sample 2 stars are overtones pulsators (Wood & Sebo 1996), while the other stars could be pulsating on the fundamental mode. Recently, van Leeuwen et al. (1997) provided modes identifications in a stellar radius vs. angular diagram (their Fig. 1): the values obtained for oxygen variables with measured angular diameters were compared to the predicted curves for the various modes. Assuming the latter lines hold for carbon variables with angular diameters (Dyck et al. 1996), our comparison points to overtones pulsation for stars in Sample 2 (Bergeat et al. 1997). These very preliminary conclusions play no role in Sect. 4 analysis.

3.2. Underluminous variables (UVs)

We have noted 12 (possibly) underluminous outliers (Sample 3) amongst the 115 stars (including 19 Miras) studied here, i.e. one tenth of the sample. The uncertainties in both periods and absolute magnitudes have to be taken into account before a firm conclusion could be reached on any individual star. In addition, the used expectations of true parallaxes by Knapik et al. (1997) are correct only in a statistical way. Despite the uncertainties, the existence of underluminous LPVs is thus confirmed, like C 2064 = RU Pup located about 3 mag. (i.e. 6 times the standard error) below the Sample 1 mean relation. This could also be the case of the Mira variable C 2165 = T Lyn but the gap is only two standard errors here. It is interesting to note that 4 stars out of 12 are Miras, two being CS-stars; also found the peculiar star C 1653 = BM Gem with strong $10\,\mu{\rm m}-$ emission which is presumably a carbon star with silicate dust in its circumstellar shell (e.g. Little-Marenin 1986). This latter star and 2 Miras are however only marginally underluminous. The faintest stars here are hardly explained with standard TP-AGB evolution (e.g. Straniero et al. 1997). We have also computed the velocities relative to sun making use of the HIPPARCOS proper motions and parallaxes, and of radial velocities observed from ground. Keeping off the exceptional 319 km/s of V Ari (which falls in Sample 2 close to Sample 1 ul) we obtained mean velocities of 30-40 km/s for the three samples. In addition, none of those stars seems to be metal deficient. Clearly, there is no marked population difference between the three samples. No significant difference between samples was found in terms of spectral types or color indices like J-K, or more generally making use of the CV-classification of Knapik & Bergeat (1997). Their mean bolometric magnitudes should significantly differ.

4. The PL relation and LMC distance modulus

The PL relation of Miras can be used to determine the distance modulus to LMC (van Leeuwen et al. 1997). Here, we calculate the slopes and zero-points of the mean PL relation for Sample 1. Some care is needed since gaussian parallax errors propagate

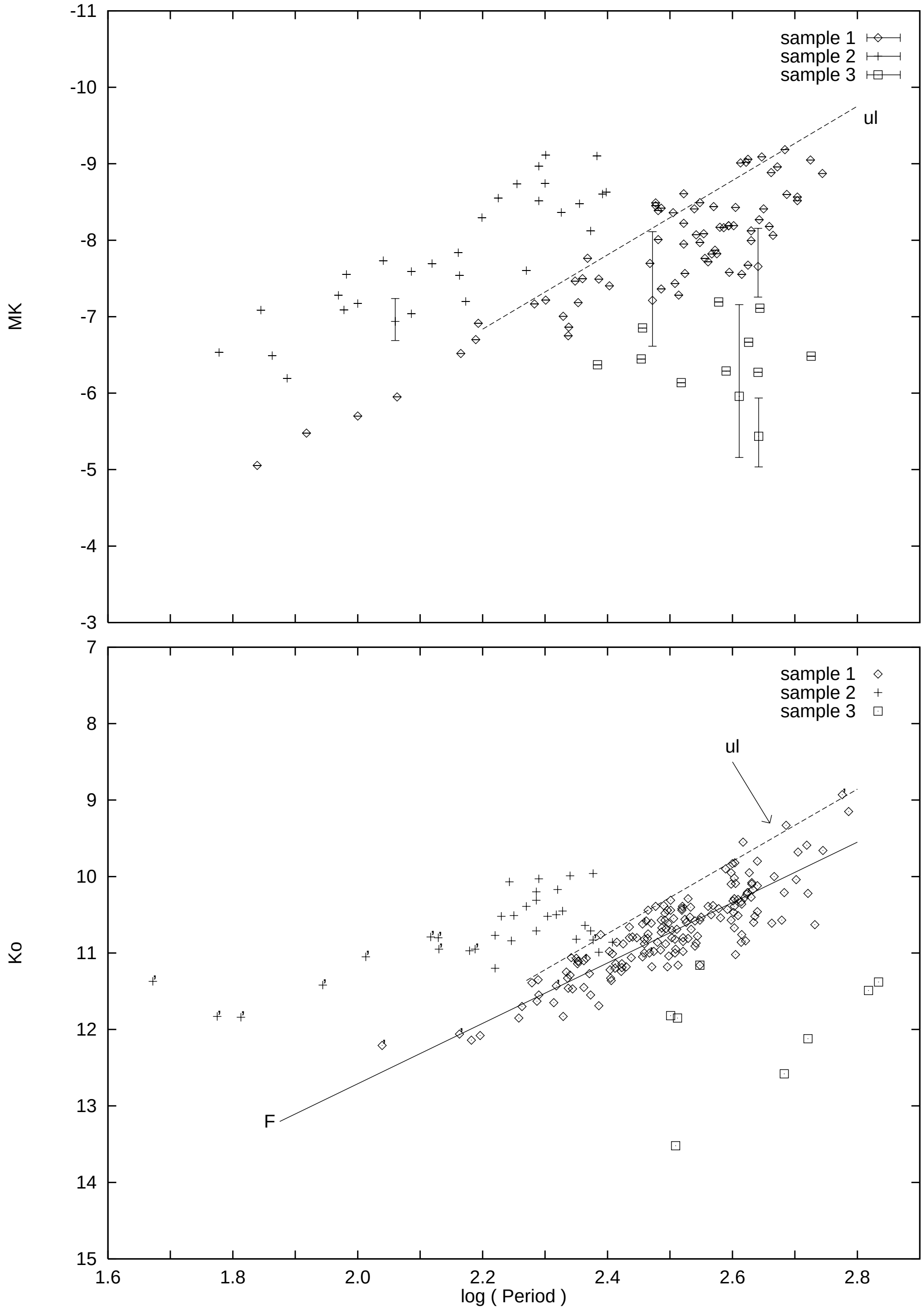

Fig. 1. The (M_K, log P) diagram for galactic (upper panel: corrected HIPPARCOS data) and LMC (lower panel) carbon variables. The PL relation of Feast et al. 1989 is shown as the continuous line while the upper limit (ul) for Sample 1 is the dashed line (see text for details).

into non-gaussian errors in distances or absolute magnitudes and a bias may result (Smith & Eichhorn 1996). To avoid this, one can write:

$$y = f(x) = \exp(a\,x + b) \tag{1}$$

where $x = \log P$, $y = \varpi\,10^{0.2\,K_0}$, $a = 0.2\,\ln(10)\,s$, and $b = 0.2\,\ln(10)\,[M_{\rm K,1d} + 10]$. The estimated true annual parallax of the star, ϖ in mas, is taken from Table 1. The mean (variations) dereddened apparent magnitude is K_0, the mean (stat.) absolute magnitude is $M_{\rm K,1d}$ that a 1 day-period star would have, and s is the slope of the PL relation. A non-linear fit of Eq. (1) was computed from the E04HFF routine of the NAG software to minimize:

$$S = \sum_{i=1}^{i=n} w_i^2\,\left[y_i - f(x_i)\right]^2 \tag{2}$$

where the $w_i^2\,'s$ are the data weights. We have used successively $w_i^2 = 1/n$ (unweighted) and $w_i^2 = K/(\Delta\,y_i)^2$ where K is a constant, which is the usual choice. Having derived a and b, the corresponding s-value is replaced in:

$$10^{\,0.2\,M_{\rm K,1d}} = \varpi\,10^{\,0.2\,(K_0 - s\,\log\,P - 10)} \tag{3}$$

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Table 2. The PL-relation of galactic and LMC carbon LPVs (s is the slope, $M_{\rm K,1d}$ the intercept and n the number of stars). Eq. (3): slope vs. ϖ, intercept and correlation coefficient.

Solution	n	s	$M_{\rm K,1d}$	μ or source
PL GAL.	72	-3.99 ± 0.13	2.07 ± 0.15	18.50 ± 0.17
PL LMC	223	-3.95 ± 0.15	20.61 ± 0.20	Fig. 1b
PL LMC	170	-3.95 ± 0.11	20.54 ± 0.27	Reid et al
Eq. (3)	72	0.02 ± 0.08	2.68 ± 0.50	Corr. C. 0.001

and the absence of correlation between the computed right hand side and ϖ is checked for. The best results were obtained from weighted data and the corresponding values of s and $M_{\rm K,1d}$ are given in Table 2. Fits in Fig. 1b (C-LPVs from references in Sect. 3.1) and from Reid et al. (1995, O- and C-LPVs) are also given which show nearly identical s-slopes for the Galaxy and LMC. It is thus advisable to deduce the LMC distance modulus by difference of the intercepts. We obtain 18.50 ± 0.17. No correction was applied for metallicity as suggested by current evidence from various stellar systems (Feast et al. 1996). The modulus quoted in Table 2 would otherwise be a lower limit. The slopes of the upper limit (ul in Fig. 1) were similarly calculated (Figs. 1a: 22 stars including 14 with appreciable weight and 1b: 13 stars). Values of -4.85 in the Galaxy and -4.72 in the LMC were found. No estimate of the distance modulus is attempted here.

5. Conclusion

We have presented the PL-diagram of field carbon LPVs from HIPPARCOS parallaxes, making use of 115 stars including 19 Miras. By qualitative comparison to the LMC diagram, we considered three samples (LPVs close to the PL relation = Sample 1, overluminous short period LPVs = Sample 2 and underluminous long period LPVs = Sample 3). The faintest LPVs of Sample 3 raise severe constraints on current models of TP-AGB stars. They might be the low-mass remnants $(\leq 0.8\,{\rm M}_\odot)$ of infrared carbon stars with $1-3\,{\rm M}_\odot$ initial masses, left over after extensive mass loss. The slopes of the PL-relations are found similar in both the Galaxy and LMC. The derived distance modulus to LMC (18.50 ± 0.17) is in excellent agreement with a previous study on oxygen-rich Miras $(18.54 \pm 0.18$, van Leuwen et al. 1997), and in reasonable agreement with the value from Cepheids $(18.7 \pm 0.1$, Feast & Catchpole 1997).

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