OXYGEN-RICH MIRA VARIABLES: NEAR-INFRARED LUMINOSITY CALIBRATIONS POPULATIONS AND PERIOD–LUMINOSITY RELATIONS

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ABSTRACT

Hipparcos astrometric and kinematical data of oxygen-rich Mira variables are used to calibrate absolute near-infrared magnitudes (broad-band K and narrow-band photometric measurements at 1.04 μm) and kinematic parameters. Three distinct classes of stars with different kinematics and scale height have been identified. The two most significant groups present characteristics close to the ones usually assigned to extended/thick disk–halo population and old disk population respectively, and thus they might differ by their metallicity abundance. Two parallel period–luminosity relations are found in K as well as in 104, one for each significant population. The shift between these relations is interpreted as the consequence of the effects of metallicity abundance on the luminosity.

Key words: Mira variables; populations; period–luminosity relations.

1. INTRODUCTION

Mira variables, due to their intrinsic brightness and large range of their ages, mark a unique stage in stellar evolution of intermediate-mass stars and thus are important in the study of stellar populations in our Galaxy. Knowledge of their distances is crucial to understand the Galactic structure evolution as well as the pulsational properties of these stars. The existence of infrared and bolometric period–luminosity relations for Mira variables is attested in the Large Magellanic Cloud (see, e.g., Feast et al. 1989). Now, the release of Hipparcos data enables one to proficiently investigate the period–luminosity relations for Galactic Mira variables.

The results presented in this paper constitute the application of the LM (Luri et al. 1996) method to Hipparcos data concerning oxygen-rich Miras. This method is based on a maximum-likelihood estimation using apparent magnitudes, trigonometrical parallaxes, proper motions and radial velocities. It has been applied to two different samples of about one hundred oxygen-rich Miras for which two sets of near-infrared (K and 104) magnitudes at maximum have been compiled from different authors. These apparent magnitudes complement the kinematical data: the trigonometric parallaxes and proper motions are obtained from the recently available Hipparcos Catalogue (ESA 1997) and the radial velocities from the Hipparcos Input Catalogue (Turon et al. 1992).

2. THE LM METHOD

The reader is referred to Luri et al. (1996) for a thorough description of the LM method. We outline here its most important features. This method, based on the maximum-likelihood principle, allows us to simultaneously calibrate the luminosity and determine the mean kinematic characteristics and spatial distribution of a given sample. This sample is specifically modeled with appropriate distribution functions corresponding to the absolute magnitudes, kinematics and spatial distribution. Sampling effects, the galactic differential rotation and observational errors are rigorously taken into account by including appropriate functions in the density law describing the sample. The method is able to use inhomogeneous samples, i.e. samples composed of a mixture of groups of stars with different luminosity, kinematics or spatial distribution. In this case the method identifies and separates the groups. Moreover, the LM method assigns each star to a group and estimates its most probable distance. The following distribution functions have been adopted:

1. Distribution of absolute infrared magnitudes: a Gaussian law with mean M_0 and standard deviation σ_M;
2. Velocity distribution: a Schwarzschild ellipsoid with means (U_0, V_0, W_0) and dispersions $(\sigma_U, \sigma_V, \sigma_W)$;
3. Spatial distribution: an exponential disc with scale height Z_0.

3. THE DATA

In this work, we focus on oxygen-rich Miras with available data in Hipparcos Catalogue: they constitute a first sample of nearly 200 objects. We decided to also include oxygen-rich semi-regular (SR) variables in order to produce more reliable estimations. The SR variables are very similar to the Miras: they are arbitrarily discriminated from Miras according to their smaller visual amplitude, but, as observed in the Large Magellanic Cloud (Hughes & Wood 1990), their absolute magnitude distributions should be similar. We have checked *a posteriori* that the oxygen-rich SR and the M–Miras of our sample actually exhibit similar kinematics and luminosities. The so-defined sample is thus kinematically homogeneous so that the LM method could be used with benefit. The trigonometric parallaxes and proper motions of the initial sample are obtained from the Hipparcos Catalogue (ESA 1997). They are complemented with radial velocities (Hipparcos Input Catalogue; Turon et al. 1992) and with:

1. apparent K magnitudes at maximum luminosity compiled from different sets of K–band observations available in the literature: Catchpole et al. (1979); Fouqué et al. (1992); Whitelock et al. (1994); Kerschbaum & Hron (1994) and Kerschbaum (1995);
2. apparent 104 magnitudes at maximum luminosity. The 104 filter forms part of a five-colour narrow-band photometric system used by Lockwood (1972). He observed 256 M–Mira variables and 11 SR stars for a total of over 1500 sets of measurements. The peak wavelength of the 104 filter is 10 351 Å, and the half-power bandwidth is 125 Å. This narrow-band filter matches a region relatively free of molecular absorption (Wing 1967; Alvarez & Plez 1997) and hence can be considered as a reliable measurement of 'continuum'.

The two final samples are coincidentally both composed of 103 Mira variables, plus 129 SR and 8 SR for the K and 104 sample respectively. Seventy variables (64 Miras and 6 SR) belong to both of them.

4. POPULATIONS SEPARATION

Wilks test indicates that the three group solution is the optimal one for both samples. Three distinct classes of stars with different kinematics and scale heights have so been identified. Tables 1 and 2 give the maximum-likelihood estimates of the parameters for the K and the 104 sample respectively. In these tables, the estimates of the parameters are given in the columns marked θ and the corresponding errors are given in the columns marked σ. These errors were calculated using Monte-Carlo simulations: simulated samples were generated and LM estimations were performed with them. The dispersion of these estimates was taken as the error on the results.

The two sets of kinematic parameters are in good agreement given the estimation errors. It is extremely satisfactory to obtain such a good agreement despite the uncertainties inherent to any statistical method, and despite the fact that the majority of both samples differ. Among the 70 common variables, only 8 are classified in discrepant groups.

Table 1. Model parameters using $m_{\rm K}$.

		group 1		group 2		group 3	
		θ	σ	θ	σ	θ	σ
M_0	(mag)	-6.3	0.7	-6.1	1.6	-6.7	0.9
σ_M	(mag)	1.0	0.4	0.4	0.4	0.8	0.5
U_0	(km s^{-1})	-11	6	-53	17	-33	40
σ_U	(km s^{-1})	37	8	1	7	93	34
V_0	(km s^{-1})	-23	6	-57	74	-93	53
σ_V	(km s^{-1})	22	4	15	30	75	24
W_0	(km s^{-1})	-12	4	-33	10	-2	33
σ_W	(km s^{-1})	20	5	3	4	58	31
Z_0	(pc)	260	40	370	180	820	240
%		81	7	2	1	17	7

Table 2. Model parameters using m_{104}.

		group 1		group 2		group 3	
		θ	σ	θ	σ	θ	σ
M_0	(mag)	-5.3	0.4	-5.5	1.5	-5.6	0.9
σ_M	(mag)	0.9	0.2	1.0	0.9	1.0	0.5
U_0	(km s^{-1})	-14	8	-51	12	-32	40
σ_U	(km s^{-1})	45	13	2	2	117	45
V_0	(km s^{-1})	-21	7	-41	9	-123	42
σ_V	(km s^{-1})	25	7	5	2	41	31
W_0	(km s^{-1})	-9	4	-34	19	-8	37
σ_W	(km s^{-1})	20	9	14	4	75	37
Z_0	(pc)	400	130	160	80	2630	1020
%		73	8	6	3	21	8

Two significant populations are well separated. Group 1, which is the main one (about 75 per cent of the sample), has the kinematics of late disk stars. The scale height is characteristic of the old disk population. This group can be interpreted as the standard 'thin disk' population which has an exponential scale height of ~ 300 pc (Jura & Kleinmann 1992).

Group 3 (about 20 per cent of the samples) has a larger velocity ellipsoid. The scale height is much more important. The very large scale height in Table 2 is an artifact of the method: it only means a spherical spatial distribution. The large velocity ellipsoid and the important scale height characterizes a population older than the group 1. They might belong to the extended/thick (E/T) disk or they might be halo stars.

Group 2 is a very small group with very low velocity dispersion. They might form a sub-population of younger stars. The small number of stars prevents further interpretation.

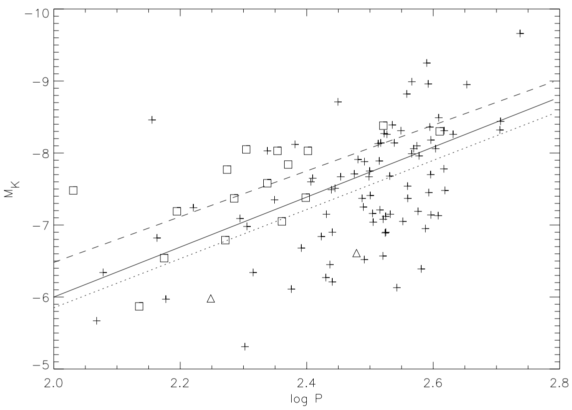

Figure 1. Period–luminosity relations in K band. Crosses represent Miras belonging to group 1, triangles to group 2 and squares to group 3. Dotted line and dashed line are the period–luminosity fit relations for group 1 and 3 respectively. Solid line is the period–luminosity relation determined by van Leeuwen et al. (1997).

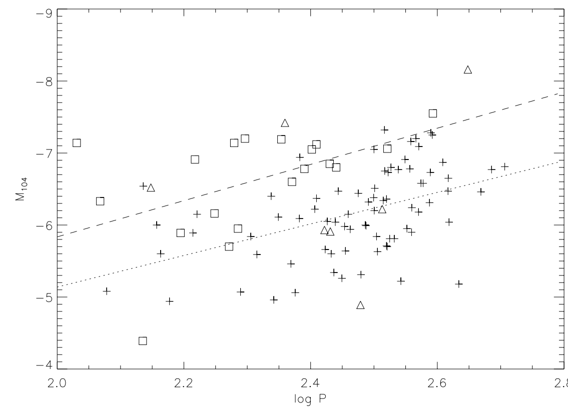

Figure 2. Period–luminosity relations in 104 filter. Crosses represent Miras belonging to group 1, triangles to group 2 and squares to group 3. Dotted line and dashed line are the period–luminosity fit relations for group 1 and 3 respectively.

5. PERIOD–LUMINOSITY RELATIONS

The individual absolute magnitudes of Miras can also be obtained with the LM method. Two parallel period–luminosity relations are found in K as well as in 104, one for each significant population (see Figures 1 and 2). The three groups are distinguished by different symbols. For the two most significant groups (1 and 3), least-square linear fits are obtained.

Figure 1 also shows the $M_{\rm K}$—P relation that van Leeuwen et al. (1997) have calibrated for Galactic O–rich Miras by using Hipparcos parallaxes and adopting *a priori* the slope of the Large Magellanic Cloud (LMC) relation. Its slope is in very good agreement with ours. This is a very remarkable result: we find that the slopes of the Galactic period–luminosity relations in K are the same as the LMC one.

It has been discussed for a long time as to whether metallicity effects in Miras might generate different period–luminosity relations. The results of the present work tend to demonstrate that Galactic Miras follow different period–luminosity relations, both in K and in 104, according to the two distinct populations that we have separated: the slopes are the same and only the zero points differ by about 0.5 mag in K and 0.8 mag in 104.

According to Wood (1990), changing Z from $Z_\odot$ to $Z_\odot/4$ will shift $M_{\rm K}$ by 0.25 mag. Assuming that the magnitude is related to the metallicity by a power law, a shift by 0.5 mag in K corresponds to a metallicity of $Z_\odot/16$ for the Miras of the E/T disk–halo population, which value is not striking. The shift between the period–luminosity relations is thus interpreted as the consequence of the effects of metallicity abundance on the luminosity.

6. CONCLUSION

In this work we have made use of a powerful tool – the maximum-likelihood LM method – applied to Hipparcos data and near-infrared apparent magnitudes for a large sample of Mira variables. In K as well as in 104, we separate three populations which exhibit different kinematics and exponential scale heights. The two most significant populations can be interpreted as the old disk population and the extended/thick disk–halo population respectively. So they probably differ by their metallicities.

Two parallel period–luminosity fit lines are obtained in K as well as in 104. The slope in K is very similar to the one observed in the LMC (Feast et al. 1989). The Galactic period–luminosity relation calibrated by van Leeuwen et al. (1997) lies between our two fits. The shift between our period–luminosity relations is probably due to metallicity effects. We stress the necessity to take into account the possibility of distinct populations when deriving period–luminosity relations for the Galaxy.

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