PERIOD CHANGES OF MIRA VARIABLES IN THE M16-M17 REGION

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Abstract: We analyzed the light curves of 165 AGB variables, mostly Miras, in the sky area centered between M16 and M17 ($l = 16$, $b = 0$), using the OGLE GVS database in the I_C band. Comparison with the published light curves, derived about 50 years earlier by P. Maffei using Kodak I-N photographic plates, allowed us to find no significant period changes in any star. Remarkably, a few stars of the sample appear to have substantially changed their average luminosity, the most striking case being KZ Ser. We provide a better identification for three stars: IX Ser, NSV 10522, and NSV 10326, all of them being Miras. We classify the light curves of 6 stars, discovered but not classified by Maffei, (GL Ser, NSV 10271, NSV 10326, NSV 10522, NSV 10677, and NSV 10772) five of them being new Miras, and confirm the R CrB nature of V391 Sct. The magnitude scale used by Maffei is compared to the modern I_C one.

keywords: Stars: AGB and post-AGB; Stars: late type

1 Introduction

The red Long Period Variables (LPV) are stars on the Asymptotic Giant Branch (AGB), in evolution towards the planetary nebula phase. They are historically classified as Mira stars if they have a luminosity variation with a rather regular amplitude and a nearly constant period, or as semiregular (SR) if the amplitude and/or the period is not so regular. Until recently there was no definite numerical threshold to distinguish between these two light curve shapes: a proposal in this sense was made by Soszyński et al. (2013). It is likely that in SR stars at least two periodic oscillations are present, with comparable amplitude, and that their interplay produces their less regular behavior.

An extensive search for the Mira period changes was made by Templeton et al. (2005), based on the large database provided by the American Association of Variable Stars Observers (AAVSO). Out of 547 stars, 21 were found to have definite (greater than $3\,\sigma$) period changes in one century, the available time extent of good quality light curves. Besides the well known case of T UMi, which is undergoing also a dramatic variation amplitude decrease (Molnár et al., 2019), 7 stars showed secular trends larger than 30 days/century. A similar work by Sabin & Zijlstra (2006) based on the AAVSO and AFOEV (Association Francaise des Observateurs d'Etoiles Variables) datasets for 23 Miras with periods longer than 450 days, showed the existence of small period changes in most of these stars: generally the period variation is erratic, with differences in a few cases up to 10% on a time interval of tens of years.

With the onset of robotic surveys of very large areas of the sky, very extensive databases containing many kinds of variable stars have been produced. A work by Lebzelter (2011), based on 454 good quality light curves of Mira stars from the All Sky Automated Survey (ASAS[1]), discussed the shape of their light curves, finding about 30% of the stars deviate significantly from a simple sinusoid. Both asymmetric shapes and broad maxima exist. The OGLE (Optical Gravitational Lensing Experiment) collaboration (Udalski et al., 2015) has explored the behaviour of late type variable stars in the Magellanic Clouds (Soszyński et al., 2009, 2011) and in the Galactic bulge (Soszyński et al., 2013), providing good light curves in the I_C band, besides the classical V band, and very tight period-magnitude relations. Relevant for this work is the finding that Mira variables have peak-to-peak I_C-band amplitudes larger than 0.8 mag, while SR variables have smaller amplitudes.

In this paper we search for possible period variations at 50 years distance in a set of 165 variables discovered by Maffei (1975), in the years 1967–75, in a 5×5 degrees field centered at $l = 16°$, $b = 0°$. Finding charts and folded light curves of these stars were published only recently in Maffei & Tosti (2013). This field was covered recently by the OGLE Galaxy Variability Survey (GVS), which uses the 1.3-m Warsaw telescope located at Las Campanas Observatory, Chile. The GVS is a subproject of the OGLE survey, aimed at repeatable observations of the Galactic disk and bulge. Currently, the OGLE GVS project monitors brightness of more than one billion stars over an area of about 3000 square degrees. The telescope is equipped with a mosaic camera consisting of 32 CCD chips covering a field of 1.4 square degrees. A detailed description of the instrumentation, photometric reductions and calibrations of the OGLE data are provided in Udalski et al. (2015).

The OGLE GVS observations were taken in the years 2014–2020, allowing to check possible variations in the light curves of our sample stars at a temporal separation of about 50 years. A period change can be easily recognized if the star is a regular Mira: uncertain Miras or SRs have by definition a variable period and/or amplitude. However we studied all the stars of the sample to check for possible misclassifications or actual transitions from Mira to SR and vice versa.

Furthermore, attempting to merge the old Maffei's and the new OGLE datasets, we tried to transform the magnitude scale used by Maffei & Tosti (2013) into the modern I_C OGLE magnitudes.

We remark that, for the large majority of our stars, no further studies were published after the discovery papers.

2 Historic Maffei's Observations

The variable stars of this sample were discovered by Maffei (1975) using the Newtonian 122 cm and 65/92 cm Schmidt telescopes of the Asiago Observatory between 1961 and 1975 using photographic plates of I-N emulsion and RG5 filter, fairly reproducing the I_C band (see Section 4). A blue plate (103a-O emulsion) of the field was always taken by

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[1]http://www.astrouw.edu.pl/asas/

Maffei in the same night for comparison, but only a few of these variables were detected also in the blue band, as expected for very red stars.

The periods of these variables were later refined by Maffei, using plates with a nearly identical filter/emulsion combination, taken with the 40/50 cm Schmidt telescope of the Catania Observatory in the year 1980, with a few plates taken in 1983–84, and 1990–91. The finding charts, phase-reduced light curves, periods, epoch of maximum, observed maximum and minimum brightness, were finally published by Maffei and Tosti in 1999 and later put into a digitized catalog (Maffei & Tosti, 2013), available at CDS (Vizier II/320). The number of photometric points was not the same for all stars, ranging from 49 to 143: in this respect the stars belong to two groups: one of 87 stars with a median of 57 observations, and one of 67 stars with a median of 122 observations. Besides the published papers, we found in Maffei's private library also two unpublished Thesis works (supervisor Maffei) regarding these stars: one by Mario Montalto (La Sapienza University, 1971) and one by Sergio Schioppa (Perugia University, 1983), which permitted correction of some misprints in the periods and light curve classifications. Finally, we found also the tables of the original magnitude measures, which allowed us to perform new period determinations with the same software used for the analysis of the OGLE data.

The variability type was assigned by Maffei on the basis of the light curve shape and amplitude. Overall the stars in the sample were classified as follows: 8 eclipsing stars (E or EA), 2 irregular (I), 111 Mira (M), 14 uncertain Mira (M:), 24 semiregular (SR). For 7 stars Maffei did not give a classification. For 15 stars (including the unclassified ones, the irregulars and most eclipsing stars) Maffei did not give a period. The periods were derived with the Press & Rybicki (1989) software based on the Schwarzenberg-Czerny (1996) method: accuracy for well sampled stars is quoted as a few days in Montalto's thesis. Some periods however are indicated as uncertain (marked with colon (:) in Vizier II/320 Table 3).

The coordinates of many stars of our sample were checked by Kato (2001) by comparison with the MSX5C catalog. Later, one of us (Nesci, 2018) checked the coordinates of all the stars comparing the original Maffei's finding charts with the UK Schmidt IV-N plates and the 2MASS catalog, allowing the correction of a few misprints in the original papers and a better identification of some variables; for three stars we further improved the identification during this work (see Section 3.4 below).

3   Modern OGLE observations and Data analysis.

3.1   Periods of the OGLE light curves.

Light curves for 165 Maffei's variables were found in the OGLE GVS database, with a typical sampling for each star of about 100 points over a 5-year time span, comparable to that of Maffei's light curves. The photometric errors were usually smaller than 0.01 mag. A few known eclipsing variables were excluded, as well as a few very poorly sampled stars, giving a final sample of 150 stars.

The periods of these variables and 1σ errors were measured with the Tatry code, which implements the multiharmonic analysis of variance algorithm (Schwarzenberg-Czerny,

Table 1: Light curve parameters from OGLE data

SIMBAD ID	2MASS ID	OGLE ID	Maffei ID	Per days	errP days	Epoch MJD	Max mag	Min mag
FZ Ser	18080193-1444151	OGLE-BLG-LPV-258610	M173	243.1	0.4	56939	12.5	15.7
GG Ser	18081103-1434279	OGLE-BLG-LPV-258664	M101	362.1	0.8	56879	10.8	12.2
GH Ser	18082202-1524048	OGLE-BLG-LPV-258711	M030	276.3	0.5	56917	12.1	14.2
GI Ser	18082639-1535119	OGLE-BLG-LPV-258733	M090	252.1	0.5	56963	11.2	14.0
GK Ser	18082549-1418077	OGLE-BLG-LPV-258729	M103	373.1	0.4	57123	13.6	16.1
.....	....	....	...	....	....	...	...	..

1996). The median error of our periods estimates is 0.76 days, with standard deviation of the distribution 0.66 days.

We computed the epoch of maximum and variation amplitude with a simple sinusoidal fit using the Period04 code (Lenz & Breger, 2005), assuming the period given by the Tatry code. The epoch of maximum was used to test the predictions of Maffei's ephemeris, and the variation amplitude to check for possible major changes in the light curve behaviour, keeping in mind the case of T UMi.

While our paper was nearly finished, the OGLE team published a large catalog of Mira variables found in the galactic bulge and disk, including most of our stars (Iwanek et al., 2022). The periods and amplitudes given in this catalog are consistent with ours within the observational uncertainty: the few discrepant cases will be discussed in the next Section.

In Table 1 we present for each star the SIMBAD name, the 2MASS counterpart, the identifier from the OGLE Collection of Variable Stars (OCVS), Maffei's number, our period, the formal error, the epoch of maximum, the observed maximum and minimum magnitudes rounded at 0.1 mag. For the stars not present in the OGLE catalog we give the internal identifier of the light curve in OGLE database. A Period=0 or err=0 means no actual measure for lack of enough data. No error is also given for the very short-period variables found.

We remark that for stars with period around one year (350–380 d, about 20 stars) there may be a period ambiguity between one year and half year due to the seasonal gap, which is rather large despite the telescope location in the Southern Hemisphere: this gap is even larger in the historic Maffei's data.

The histogram of the derived amplitudes for the Mira and SR stars is given in Fig. 1 and shows no difference between these two classes, so that it cannot be used to discriminate between them. The puzzling result of this plot is that nearly all stars have amplitude larger than 0.8 mag in I_C, including those classified by Maffei as SR, suggesting that all of them should actually be considered as Miras according to the simple criterion of variation amplitude ≤ 0.4 mag (Soszyński et al., 2013).

The periods histogram (Fig. 2) shows a little prevalence of longer periods for the stars classified by Maffei as Mira, but the overlap of the two distributions is quite large, again suggesting a revision of the classification.
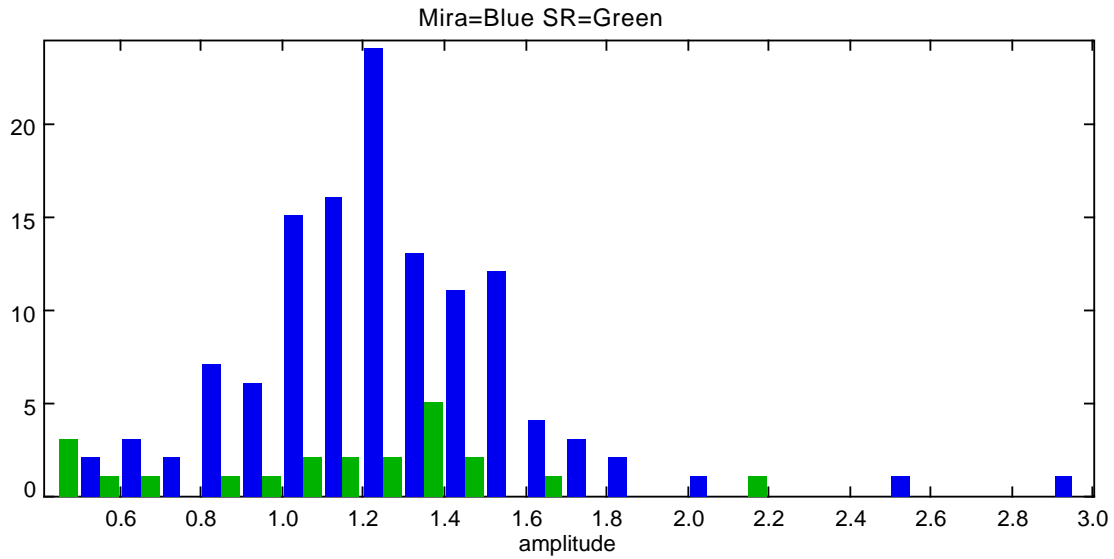
Figure 1: Distribution of variability amplitude based on the OGLE light curves for stars classified by Maffei as Miras and SR variables.
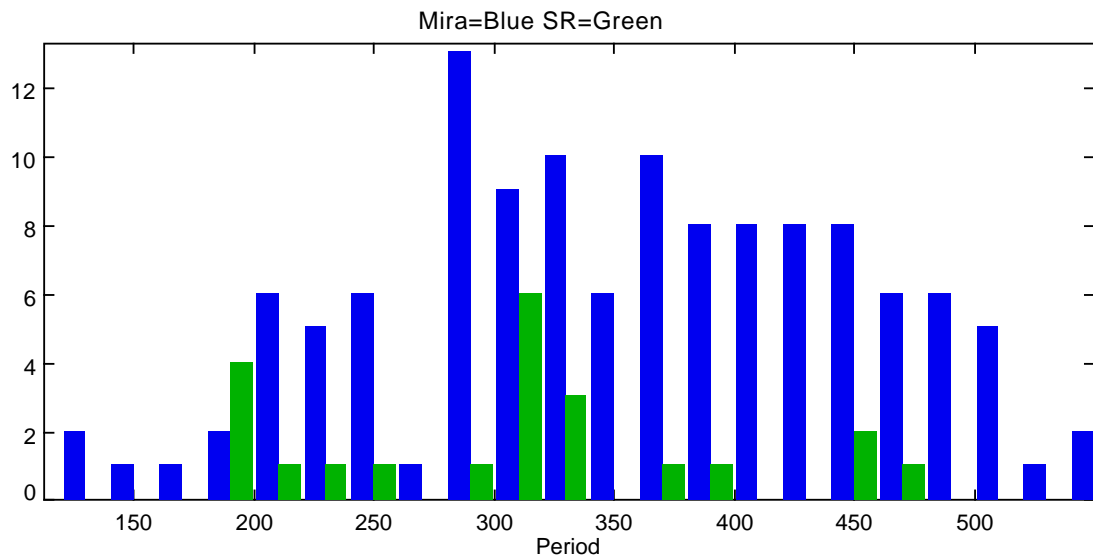

Figure 2: Distribution of periods based on the OGLE light curves for stars classified by Maffei as Miras and SR variables.
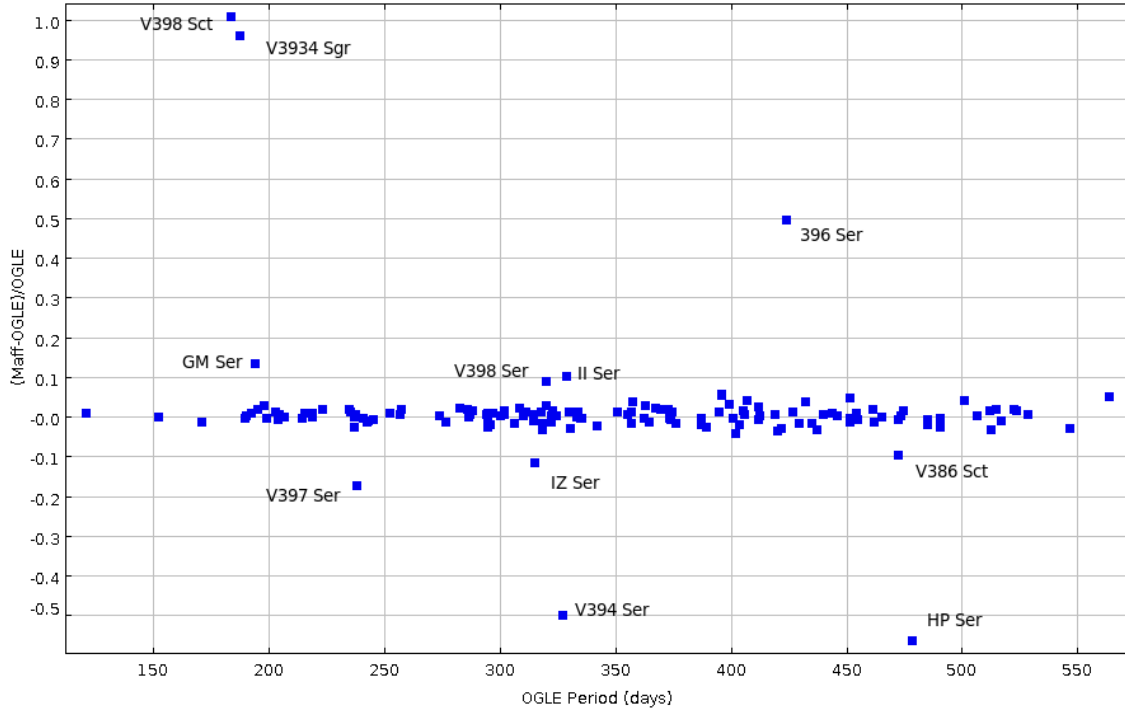
Figure 3: Ratio of the differences between Maffei's and OGLE period to the OGLE period ($\Delta P/P$), vs the OGLE period. Stars that exhibit a large period discrepancy are labelled and discussed in the text.

3.2   Comparison of Maffei's and OGLE periods.

Having derived the present periods of our stars from the OGLE GVS database, we plot in Fig. 3 for each star the ratio of the difference between Maffei's and OGLE period to the OGLE period ($\Delta P/P$): most of the stars show very consistent results, indicating that no significant period changes happened between the two observation campaigns.

Having found in Maffei's archive his original magnitude measures, we used our Tatry code to derive new period determinations from the old Maffei's observations, to check the effect of using a different code on the period determination: these new period measures were largely consistent with the original ones. Indeed, for a subsample of 129 stars the average difference between the two measures was just 0.21 days (and the median difference even smaller, 0.09 days); the rms scatter was 2.88 days and the maximum period difference found was 13 days, i.e. 5σ. For 6 stars the difference was about a factor 2 or 3, suggestive of period aliases taken as actual periods. For 8 stars the difference was larger than 20 days, anyway below 14% of the period. In 4 cases the Tatry code did not converge to give a Period.

Another way to look for period changes, besides the simple numerical comparison, is to check if the OGLE ephemeris (period and epoch of maximum) predicts correctly the date of Maffei's epoch (or vice versa). The number of cycles for our variables between the years 1967 and 2014 ranges from about 30 (for a 500 d period) to 70 (for a 200 d period), so that an error of one day (the typical OGLE error) in the period produces a difference

of about one to two months in the computed epoch, and a phase difference ranging from 0.06 to 0.28. The accuracy of Maffei's epochs is not declared, and we assume it should be about one week from the shape of a typical Mira light curve.

We made this test computing the expected phase of each light curve at Maffei's epoch, finding a nearly flat distribution between -0.5 and 0.5 instead of a clustering around phase zero as expected if the periods were nearly constant. The same happened computing the expected phase of the light curve at the OGLE epoch using Maffei's ephemeris.

However, given the large number of cycles between the two epochs, a small difference in the adopted period could easily adjust the phase to the nominal value. Indeed we computed for each star an average period, using as time base the interval between Maffei's and OGLE epochs of maxima, and a number of cycles nearest integer to that derived from the OGLE period. Given the very large time base (of the order of 16400 days) and the 365 days length of a typical period, the formal accuracy of these average periods would be about 0.01 days, even if the epoch uncertainty is assumed 2 weeks. If the period were stable, the period computed in this way should be very similar (within a few σ) to the OGLE one, measured on a 4 year time base.

We made this test, finding periods differences $\leq 3\sigma$ for 111 stars, $\leq 4\sigma$ for further 10 stars, and $\geq 5\sigma$ for 14 stars.

As told in the Introduction, fluctuations of a few percent are rather common in Mira variables over tens of years, so we will discuss in detail only the apparently very discrepant stars.

For the large majority (104/111) of the Mira stars the period percent difference ($\Delta P/P$) between OGLE and Maffei was less than 0.04, with rms deviation 0.02, indicating that no significant changes happened in 50 years: only two Miras showed a period discrepant by more than 5%.

Out of the 14 Maffei's probable Miras (M:) only one showed a significant difference.

Out of the 24 SR, two do not have a period by Maffei; three showed a marked period variation ($\Delta P/P \geq 0.5$), whereas three others have $\Delta P/P$ about 0.1. It is remarkable that so many (6/24) stars classified by Maffei as SR have a significantly different period, observed 50 years later, compared with the (2/111) Miras. This may suggest that the criterion to discriminate Miras and SRs just from the light curve amplitude may not be completely sufficient.

Finally, Maffei labelled 8 stars as eclipsing variables, but only 4 have a period reported, always very long, ranging from 196 to 592 days. From their OGLE light curves these four stars are classified as follows: GM Ser is an R CrB star; V374 Sct is a Mira with a period similar to Maffei's one; V382 Sct has only 50 points in OGLE but looks rather irregular; V397 Ser looks a SR. Of the remaining four stars, two are actually short-period eclipsing stars (NSV 10497, $P = 4.11316$ d; NSV 10681, $P = 1.84228$ d); one is a Mira (NSV 10249, $P = 191.5$ d); one looks a SR (NSV 10832, $P = 320$ d).

3.3 Discrepant stars

The most period-discrepant stars are listed in Table 2, grouped according to the original Maffei's classification, and their OGLE light curves are shown in Fig. 4. We report in
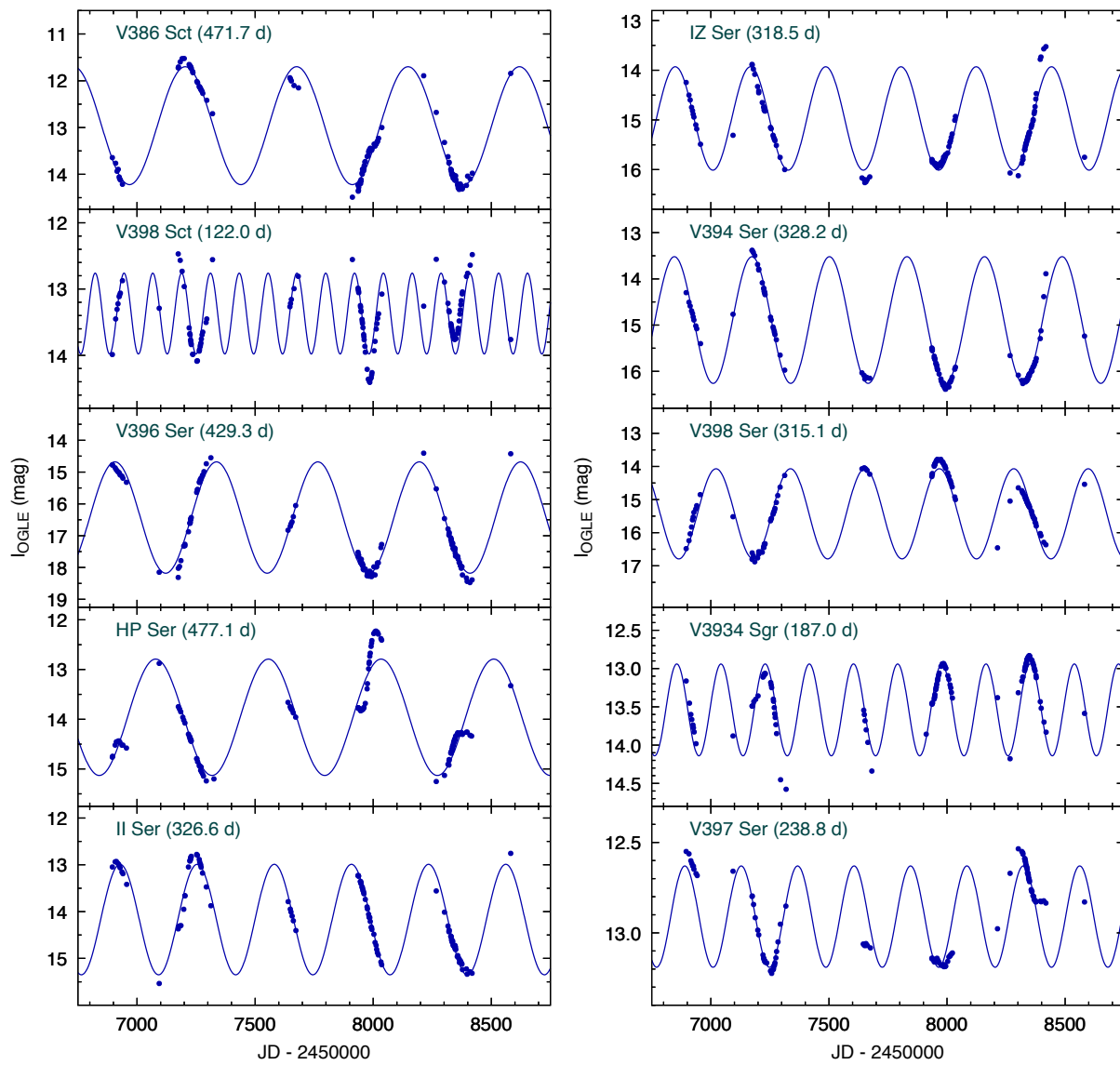
Figure 4: OGLE photometry with fitted light curves for the period-discrepant stars.

Table 2: Stars with discrepant periods

Name	Maffei	OGLE	Cl.	P_{Maffei} d	P_{OGLE} d	errP d	$\Delta P/P$
V386 Sct	M026	OGLE-BLG-LPV-263898	M	426	472.4	1.0	-0.097
V398 Sct	M145	OGLE-BLG-LPV-264150	M	368	183.3	0.4	2.016
V396 Ser	M132	OGLE-BLG-LPV-261077	M:	633:	423.9	1.41	0.474
HP Ser	M093	OGLE-BLG-LPV-259581	SR	208	478.1	1.1	-0.564
II Ser	M041	OGLE-BLG-LPV-259900	SRa	362	328.7	0.8	0.108
IZ Ser	M178	OGLE-BLG-LPV-260964	SR	278	314.8	1.1	-0.127
V394 Ser	M046	OGLE-BLG-LPV-260384	SR	163	326.9	0.4	-0.503
V398 Ser	M186	OGLE-BLG-LPV-264150	SR	348	319.9	1.5	0.104
V3934 Sgr	M109	OGLE-BLG-LPV-262824	SRa	366	187.0	0.4	0.957
V397 Ser	M175	BLG780.16.28126	EA	196	237.8	0.7	-0.179
GM Ser	M092	BLG766.05.11	E	219	193.8	0.8	0.132

column 1 the SIMBAD name; in column 2 Maffei's number; in column 3 the OGLE identifier; in column 4 Maffei's classification; in column 5 Maffei's period; in column 6 the OGLE period; in column 7 the formal OGLE period error; in column 8 the ratio of the periods difference to the OGLE period ($\Delta P/P$).

We examined more in detail these stars to see if they really underwent a period change, and are discussed below. The interactive code Peranso (Paunzen & Vanmunster, 2016) was used to interactively build phased light curves with different periods and evaluate the significance of the adopted periods.

a) Mira stars.

V386 Sct: its period is indicated by Maffei & Tosti (2013) as 426 d in their Table 3, but as 446 d in their Figure of the phased light curve. We re-measured Maffei's period with the Tatry code using Maffei's magnitudes finding 447 d, in fair agreement with the OGLE one. The OGLE light curve is nicely sinusoidal with a small rms deviation and a period of 472 d, so it does not seem a case of significant period change.

V398 Sct: the OGLE light curve shows minima of different depth and a period of half year, while Maffei gives one year. The phase-reduced light curve published by Maffei shows a large spread around the maximum phase. Maffei's data are not incompatible with the OGLE period (183 d): likely Maffei's estimate was biased by the seasonal gap and a real period change is not likely.

V396 Ser (NSV 10472): The light curve in Maffei & Tosti (2013) has only 10 points and the quoted period is tentative. The light curve in the OGLE database is well populated and rather regular, with a large amplitude (4.0 mag peak to peak) and a period not compatible with Maffei's suggestion. It can be classified safely as Mira, but it is not possible to check if a period change really happened.

b) SR stars.

HP Ser: the OGLE light curve shape shows a strong bump in the ascending branch, not uncommon in Miras, with variable level. Maffei's period recomputed with Tatry is 492 d, similar to the 478 d OGLE one, with a difference of just 3%; the variable amplitude of

the light curve, and the low accuracy of Maffei's magnitudes makes the 14 days difference not very significant.

II Ser: the OGLE light curve is quite regular, typical of a Mira. Maffei's period is not compatible with the OGLE light curve, but his phased light curve is bad. Our recomputation of Maffei's period with Tatry code gives 3 possible periods of nearly equal weights, one of them similar to the OGLE one: there is no evidence therefore of a period variation.

IZ Ser: the OGLE light curve is well behaved and Mira-like but with variable amplitude. Our recomputation of Maffei's period with Tatry gives the same period of the OGLE data. We remark that using the Lombe-Scargle method on Maffei's original data gives the same result given by Maffei, while for the OGLE data gives nearly the same period of the Tatry code. This difference is likely due to the much larger photometric errors of the photographic magnitudes. Also for this star there is no evidence of period variation.

V394 Ser (alias NSV 10391); the OGLE light curve is well behaved and with a period double of Maffei's one. The phased light curve by Maffei shows several points at odds. Our reanalysis of his data shows several periods of nearly equal weight (164, 226, 328 d), the shortest one being Maffei's one, and the longest one being the OGLE one. Maffei's data are strongly dominated by a dense sampling, 170 days long, made in 1980. Mayby the star was correctly classified as SR by Maffei, but its behavior was quite regular during the OGLE monitoring.

V398 Ser (alias NSV 10479): Maffei's light curve has a small amplitude due to many upper limits; the OGLE period is definitely different from Maffei's one. It shows a large amplitude variation and small phase shifts, so it is likely a Carbon star, not a regular Mira.

V3934 Sgr: the OGLE light curve shows large amplitude variations between consecutive cycles. Maffei's data can be well fitted by the OGLE period or by its double with very similar significance, so there is no convincing evidence of a transition from the fundamental frequency to the first overtone.

c) eclipse star:

V397 Ser (alias NSV 10475): Maffei does not show a phased light curve of this star, classified as eclipse, and its period is flagged uncertain. The OGLE light curve shows a small amplitude (0.6 mag peak to peak) and a quite scattered phased light curve using a 238 d period. The star looks an Irregular or SR variable.

GM Ser: classified as eclipse by Maffei with spectral type M7 (Montalto's thesis); classified as CrB in SIMBAD. The OGLE light curve is well fitted by a small-amplitude sinusoid, but shows a sharp deepening and a small flare, indicative of an R CrB: therefore its light curve is not shown in Fig. 4. Tisserand et al. (2013) have contested its R CrB classification, but confirmed the spectral type M7.

3.4   Further remarks

Wrong identifications.

During the present work we found three stars with wrong identification.

NSV 10326 (Maffei M005): no period and classification were given by Maffei for this

Table 3: OGLE data for Maffei's unclassified stars

Name	Maffei	OGLE	Period	Amp.	mean I_C	Class.
			d	mag	mag	
GL Ser	M031	OGLE-BLG-LPV-258777	171	1.23	13.70	Mira
NSV 10271	M174	OGLE-BLG-LPV-258970	300	1.73	14.89	Mira
NSV 10326	M005	BLG766.18.154	315	0.93	15.31	Mira
NSV 10522	M035	OGLE-BLG-LPV-261605	456	1.97	16.19	Mira
NSV 10677	M028	OGLE-BLG-LPV-262404	394	1.13	15.32	Mira
NSV 10772	M183	BLG569.19.104	262	0.12	13.74	SR

star. The present identification in SIMBAD is with a blue star, much brighter than the value reported by Maffei; we found a source, at 20 arcsec distance, 2MASS J18110050-1423082, with quite red colors, whose OGLE light curve is typical of a Mira star with a period of 315 days. We therefore identify this star with Maffei's variable M005.

NSV 10522 (Maffei M035): no period and classification were given by Maffei for this star. The SIMBAD counterpart of M035 was found substantially constant in the OGLE data. We made therefore a new careful comparison of Maffei's finding chart with the DSS I-band plate available from the STScI and the 2MASS image from SIMBAD, finding a new candidate at 9 arcsec distance, 2MASS J18182915-1725379. The OGLE light curve showed that this star is a large amplitude Mira with a period of 457 days.

IX Ser (Maffei M179): our identification is with 2MASS J18153810-1505332, 9 arcsec off the quoted position in SIMBAD. Its OGLE light curve is typical of a Mira variable, with amplitude and period very similar to those quoted by Maffei (amplitude 1.66 mag, P=303 d).

Other variables.

Two stars were classified as irregulars by Maffei and therefore had no period measure. One of them, NSV 10899 (M024, 2MASS J18295552-1518384), has a time scale of 34 days in the OGLE data and we classify it as an RV Tau star. In the OCVS catalog its period is reported as 68 days, double than ours. The second star, V391 Sct, has an R CrB light curve and was already classified as such by Tisserand et al. (2013).

Unclassified stars.

For six unclassified stars of Maffei's sample we derived the light curve and the period from the OGLE database: we have checked the VSX database to see if they have been studied in detail after Maffei's publications, finding nothing. Five of them are Mira variables, both from the amplitude and from the period length, and one is a SR; two stars are new identifications, as discussed above. Our measures of periods, amplitudes, mean magnitudes, and classifications for these six stars are listed in Table 3.

Corrections of mistakes.

During this work we found two inconsistencies in Maffei & Tosti (2013), which are listed below.

M015, V405 Sct: the period is 307 d in Table 3 but 357 d in the light-curve Figure; in the discovery paper (Maffei, 1975) the period was 362 d. The OGLE value 359.2 d is in agreement with the original value.
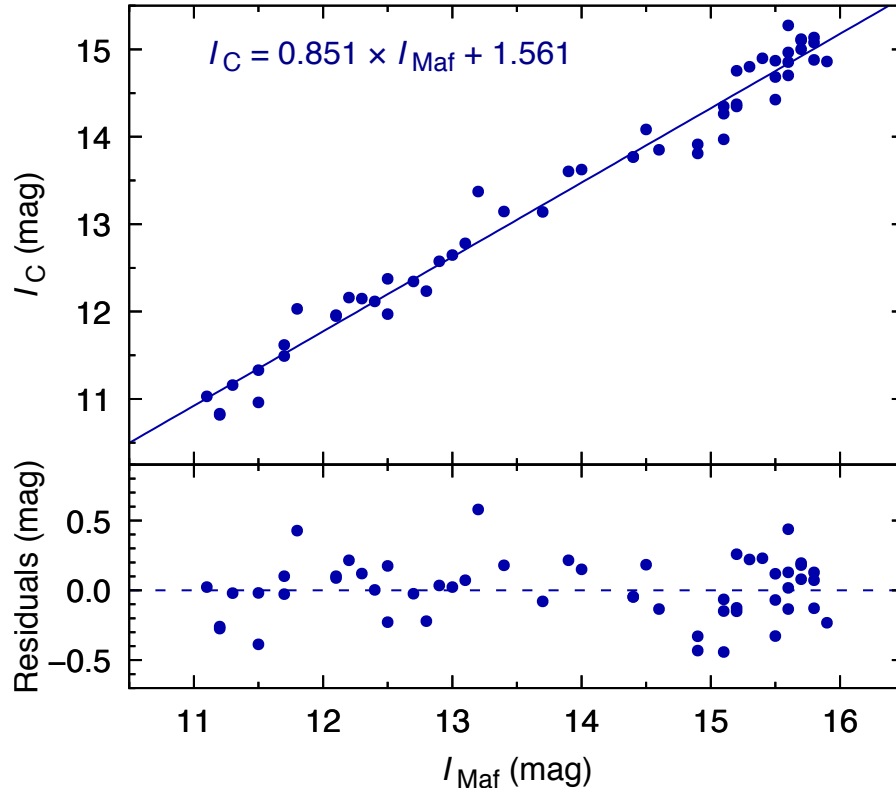
Figure 5: Comparison of the original Maffei's I magnitudes of the comparison sequence with the OGLE I_{C} magnitudes.

M203, V374 Sct: originally classified as SR by Maffei (1975) with 400 d period, and in the thesis work by Schioppa (1983) with 408 d period, from a dataset of 38 points. Later it was reclassified as E in Maffei & Tosti (2013). The OGLE data (110 points) show a Mira variable with 420 d period. Our reanalysis of Maffei's data with Tatry confirms a 409±2 d period: the difference is only 2.6%, not much relevant.

Overall, after our careful analysis, no star among those classified as regular Miras appears to have changed its period by a significant amount.

4   Comparison of the OGLE magnitudes with Maffei's ones.

After checking the periods, we tried to verify if any star had significantly changed its average magnitude or variability amplitude.

As written in Section 2, the filter and emulsion used at the Asiago Observatory to obtain infrared plates were respectively RG5 and Kodak I-N. The RG5 filter is a longpass with cutoff at 665 nm, and the red cutoff is provided by the Kodak I-N emulsion around 900 nm. The plates taken in the years 1980 and following were taken at the Catania Observatory with the 40/50/120 cm Schmidt telescope and RG695 + I-N filter/emulsion combination. According to Bessell (1979) (his Table 7), the Cousins I_{C} filter can be approximated with

photographic material with an RG 695 filter (instead of RG5) in combination with Kodak IV-N emulsion, which is the improved finer grain version of the I-N emulsion. The blue cutoff difference between these two filters is 30 nm, while the width at half maximum of the I_C filter is 110 nm, so that the bandwidth increase is about 27%. Given that the spectrum of an M-type star is monotonically decreasing blueward within the I_C band, the magnitude difference between the two filter/emulsion combinations is comparable to, or lower than, the errors of Maffei's magnitudes. Indeed, Maffei & Tosti (2013) did not make any correction when merging the datasets of the two instruments to build their light curves.

Anyway, when Maffei established his magnitude scale in 1967 the Cousins system was still not defined; therefore he established a comparison sequence on the Asiago plates with an approximated Johnson's I magnitude derived by extrapolating the UBV magnitudes of 60 stars of the Walker (1961) sequence in the open cluster NGC 6611, which is located near the center of Maffei's field.

We found more details, including the actual list of the stars and their adopted magnitudes, in Montalto's thesis. Instrumental magnitudes for these comparison stars were derived by Maffei with the Becker iris photometer of the Monteporzio (Roma) Observatory and a calibration curve was built using the above mentioned infrared magnitudes. Secondary comparison sequences were then built by Maffei in selected areas of the field of view, to allow the magnitude estimates of the discovered variables, which were made by eye inspection with a microscope. The internal accuracy of Maffei's individual magnitudes is reported to be from 0.1 to 0.3 mag (Maffei & Tosti, 1995). We stress that no actual infrared standard stars were used by Maffei, so his scale is not linked to the present Cousins system.

To perform a transformation of the infrared magnitudes of Maffei's primary sequence (I_Maf) into the OGLE I_C magnitudes, we recovered from the OGLE archive the I_C magnitudes of his 60 comparison stars. The scatter plot of these OGLE magnitudes with Maffei's ones is plotted in Fig. 5, which shows a good linear correlation, namely:

$$I_\mathrm{C} = I_\mathrm{Maf} \times 0.851(\pm 0.017) + 1.561(\pm 0.239), \qquad (1)$$

with rms deviation 0.21 mag. The slope of the regression line is significantly shallower than 1.0, suggesting the existence of some systematic effect: unfortunately the stars of the Walker sequence do not contain very red stars, so that it is not possible to check the existence of a color term in the transformation from I_Maf to I_C.

To compare Maffei's magnitudes of the variable stars with the OGLE I_C ones, we transformed the original Maffei maximum and minimum magnitude of each variable star into I_C according to Eq. 1 and computed the average magnitude (($\max + \min$)/2). These average Maffei magnitudes are compared with the OGLE mean magnitudes (derived from the fit of the light curve) in the top-left panel of Fig. 6. Excluding the 10 most discrepant stars, the best fitting slope is 1.23, significantly different from the ideal case of 1.00, with an offset of about 0.5 mag at the plot center; remarkably, the spread is quite large, with an rms deviation $\sigma = 0.72\,\mathrm{mag}$ from the regression line.

The deviation of the slope from the ideal case, and the offset, might be due to a color term, which we could not evaluate given that the Walker sequence does not contain M-
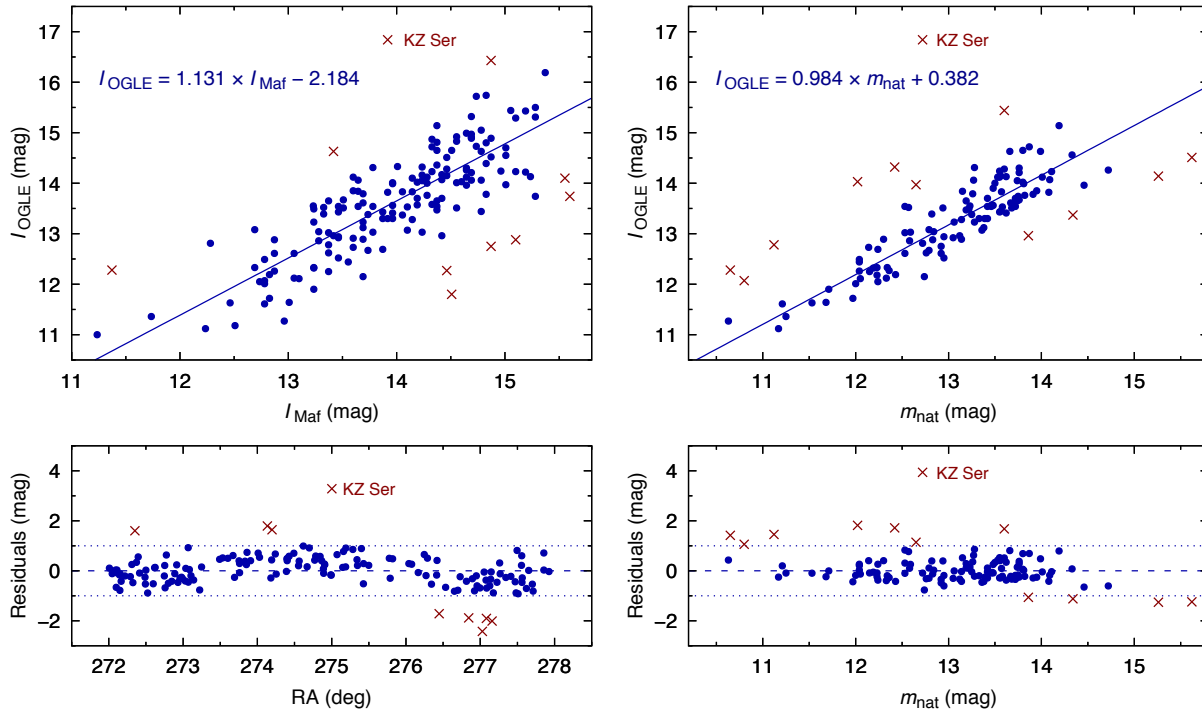
Figure 6: Relations between Maffei's and OGLE magnitudes. *Top left:* OGLE magnitudes of our variables as a function of the mean Maffei's magnitudes transformed into I_C according to Eq. 1 . *Bottom left:* residuals of the linear fit as a function of right ascension. *Top right:* I_{OGLE} as a function of mean magnitudes derived from the reanalysed light curves. *Bottom right:* residuals of the linear fit.

type stars, but it is not a concern to detect a possible large change of the mean magnitude of a given variable at ∼50 years distance. More of concern is the large dispersion of the data from the regression line.

A further source of systematic error may be the way of computing the average value: for the OGLE data it comes from the fitting of a sine curve to the whole light curve, for Maffei's data it comes from a simple average of the maximum and minimum reported values.

To understand the reason of the large spread we plotted the magnitude differences as a function of the celestial coordinates, finding a significant trend in RA (see Fig. 6, bottom left). A possible reason of this trend could be inconsistencies among the several secondary comparison sequences actually used by Maffei for his magnitude eye-estimates. For instance, the four outlying stars around coordinates (l=277, b=-2, see bottom left panel of Fig. 6) have similar declination, so are in the same sky area, suggesting a systematic error in the local comparison sequence.

4.1   Reanalysis of photographic plates

To minimize the systematic errors expected from the inconsistencies of the secondary comparison sequences and from the way of computing the average magnitudes of the variable stars, we reanalyzed 47 Maffei's plates, obtained with the Asiago 65/90 cm Schmidt
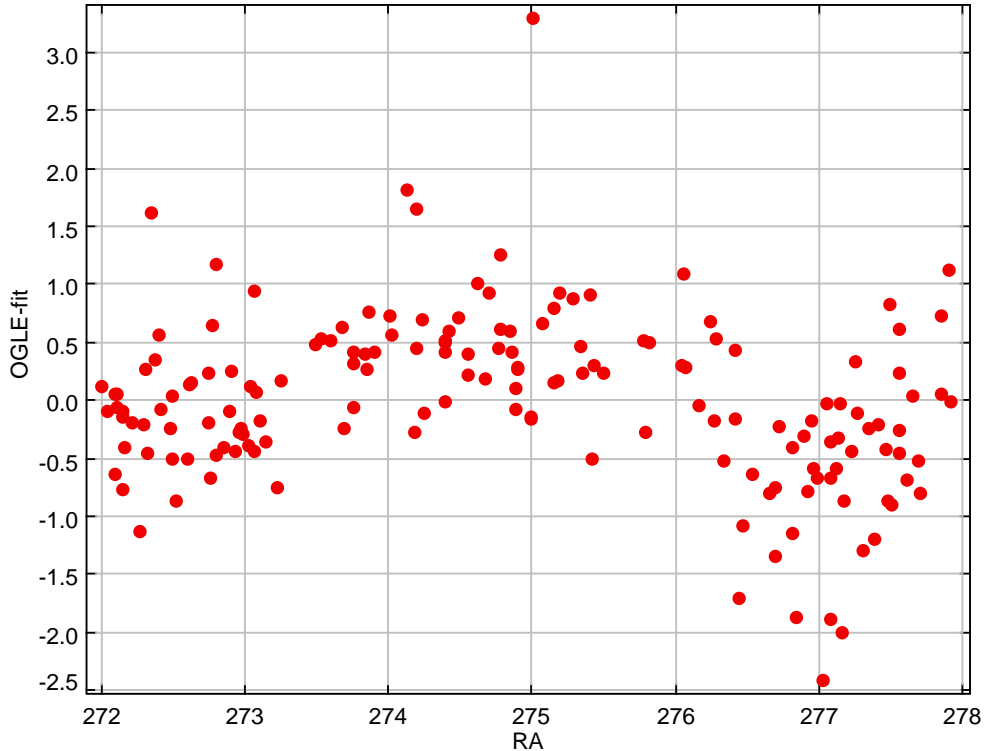
Figure 7: The distance of the OGLE mean magnitude from the regression line of Fig.6 *vs* the R.A. of the star. A systematic trend is present. The very discrepant star at the top is KZ Ser.

telescope, and digitized at 1600 dpi (1.59 arcsec/pixel). The astrometric solutions and photometric reductions were carried out using the PyPlate software, in a pipeline developed for the APPLAUSE project (Tuvikene et al., 2014).

The pipeline processed the digitized plate images in multiple steps. Instrumental magnitudes (MAG_AUTO) of all detected sources were extracted with the SExtractor program (Bertin & Arnouts, 1996). Initial astrometric solutions were derived with the Astrometry.net software (Lang et al., 2010) and refined astrometric calibration in sub-fields was obtained with SCAMP (Bertin, 2006), using reference coordinates from the UCAC4 catalog. The source list was then cross-matched with the UCAC4 and APASS DR9 catalogs. The typical internal error of the individual PyPlate measures was 0.15 mag, quite comparable to that of the original Maffei's measures, and was basically dictated by the quality of the hypersensitized I-N plates, but in some cases it was up to 0.3 mag. Further details of the procedure can be found in Nesci et al. (2018).

Photometric calibration was carried out with the Sloan r' and i' magnitudes of a large number of non variable stars taken from the APASS DR9. Each photographic plate has a unique color response that can be characterized with the color term C, as explained by Laycock et al. (2010). Magnitudes in the plate natural system, m_{nat}, are related to the standard magnitudes:

$$m_{\text{nat}} = i' + C(r' - i'). \tag{2}$$

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We determined the color term for each plate by trying a series of C values to minimize the scatter in the photometric calibration curve. The color terms varied from -0.26 to -0.04, with a mean value of -0.15. All instrumental magnitudes were then transformed to natural magnitudes: these m_{nat} are our best estimates of the Sloan i' magnitudes of the individual observations of our variables. Conversion into the I_{C} band could in principle be made using the formulas by e.g. Jordi et al. (2006) or Jester et al. (2005), but these formulas contain color indexes, which are not known for our variables. The expected approximate zero point difference can be evaluated comparing the m_{nat} magnitudes of the stars in the Walker sequence with their I_{C} magnitudes in the OGLE database: the comparison was quite satisfactory, with

$$I_{\mathrm{C}} = m_{\mathrm{nat}} \times 1.008(\pm 0.005) - 0.353(\pm 0.081). \qquad (3)$$

At first order therefore an offset of -0.35 mag should be expected. As told above in Section 4, the Walker sequence does not contain M-type stars, so possible further color term corrections for the magnitudes of our (very red) variables could be present but cannot be quantified.

Unfortunately PyPlate was in trouble for star images near the plate limit, so for many variable stars our light curve is not well populated. Anyway we were able for 128 stars to compute the mean magnitude and the variation amplitude from the sinusoidal fit of their light curve, derived in the same way as for the OGLE light curves described above in Section 3.1. Despite the actual light curves of our stars are not strictly sinusoidal, the use of the same shape for the OGLE and the Asiago data minimize systematic differences. For stars detected only during the high state, the light curve is not constrained in the faint part, so the mean magnitude and amplitude derived from the sinusoidal fit are less reliable.

For the 118 best sampled stars (good number of points well distributed in phase), the mean magnitude is compared with the OGLE one in the top-right panel of Fig. 6. The regression line shown has slope near unity and the magnitudes offset is negligible. The spread of the stars around the regression line ($\sigma = 0.61$) is reduced with respect to the plot of Fig. 6 (left), made using the original Maffei's data. This is an indication that the systematic errors due to the secondary Maffei's comparison sequences, and to the way of computing the average magnitudes, have been reduced, but remains significantly larger than the nominal accuracy of the individual measures.

The most distant stars from the best fit locus are marked in Fig. 6 and listed in Table 4 in order of mean magnitude difference.

We have checked the light curves of these stars to see if an uneven sampling could produce a strong bias. The stars above the line (positive delta mag) are all detected only around the tip of the light curve from the Pyplate pipeline, so their computed average values are unreliable. The stars below the line (brighter than OGLE in the Asiago plates) are poorly sampled with the plates available to us. After careful examination of the light curves we conclude that only two stars have a reliable difference in their mean magnitude, KZ Ser and GR Ser.

The most striking case (4 mag deviation) is that of KZ Ser. This Mira variable has one of the longest period of this sample: the variability amplitude (about 3 mag) is very

Table 4: Stars with possible change of the average magnitude.

Name SIMBAD	OGLE id	Maffei id	I_{OGLE} mag	Period d	ΔI mag	N. of plates
KZ Ser	OGLE-BLG-LPV-261988	M140	16.84	511.9	3.94	13
V414 Sct	OGLE-BLG-LPV-264442	M137	15.44	546.7	1.67	34
V3924 Sgr	OGLE-BLG-LPV-261845	M096	14.32	362.8	1.71	14
V374 Sct	BLG787.23.49	M203	14.03	421.4	1.82	23
V3927 Sgr	OGLE-BLG-LPV-261965	M097	12.78	218.4	1.45	38
GR Ser	BLG767.28.8	M164	12.28	234.9	1.41	45
V383 Sct	OGLE-BLG-LPV-263764	M061	13.97	295.5	1.14	33
V3947 Sgr	OGLE-BLG-LPV-263995	M060	12.07	308.1	1.06	41
V386 Sct	OGLE-BLG-LPV-263898	M026	12.86	472.4	-1.06	29
V398 Sct	OGLE-BLG-LPV-264150	M145	13.37	183.3	-1.12	38
GS Ser	OGLE-BLG-LPV-259041	M020	14.51	373.9	-1.24	25

similar in both datasets, as well as the shape of the light curve, with a very steep rising branch and a long decreasing branch. To check our result we found in the STScI archive two digitized infrared plates (N emulsion) of the Second Palomar Sky Survey (POSS-II) survey, taken on 1980-08-29 (MJD 44480) and 1982-04-18 (MJD 45077): the first plate is simultaneous to a Maffei's plate taken at the Catania Observatory, while there are no plates around the second date.

At the first POSS-II plate epoch the star was near its minimum (phase 0.77) according to Maffei's ephemeris: Maffei & Tosti (2013) report a magnitude I_{Maf}=16.0 which is converted to I_{C}=15.2 according to Eq. 1), in fair agreement with the GSC2.3 catalog (15.8). On the second POSS-II plate the star was at phase 0.92, on the steep rising branch, so its expected magnitude is rather uncertain. On the POSS-II plate the star was about 15.4, somewhat brighter than in the first plate, in fair agreement with the expectation. The POSS-II plates therefore confirm Maffei's observations, so we think that the luminosity drop of ∼4 mag of KZ Ser detected by OGLE is real. A possible explanation for the star fading may be extinction by a recent dust emission.

GR Ser had a brighter average magnitude at the time of Maffei's monitoring. It is covered by only one public POSS-II plate (taken on 1980-08-29), simultaneous to a Maffei's one, with I_{C}=10.88 in the GSC2.3 catalog. Maffei's value is 11.3 (rescaled as above), in fair agreement. The OGLE magnitudes range from I_{C} 9.5 to 16, while Maffei's monitoring ranged from 10.1 to 13.0 (rescaled according to Eq. 1). Overall the maxima are fairly consistent, so we guess that the different average value is due to the deep minimum detected by OGLE and missed by Maffei.

5   Infrared colors and distance estimates

Our variables are located around galactic coordinates $l = 16°$, $b = 0°$. From the map of the galactic plane by Reid et al. (2014) we expect that they belong to the Scutum and the Sagittarius arms so may be largely spread in distance form 1 to 4 kpc. They may
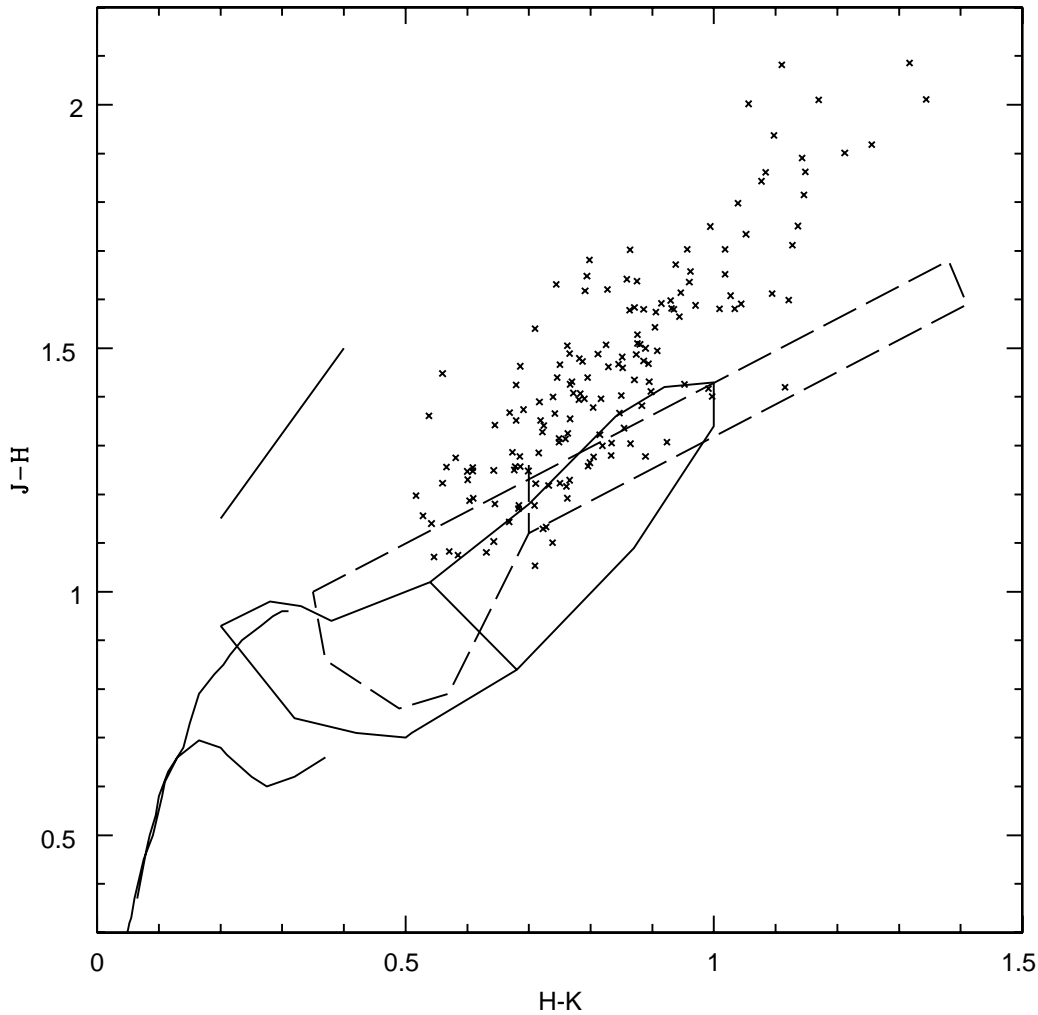
Figure 8: The NIR color-color plot of Maffei's LPVs with an OGLE period overplotted to the Bessell & Brett loci for Late Type Stars described in the text. The reddening vector for $E(B-V) = 1$ is drawn to help the eye.

therefore suffer of different absorptions, of the order of 1 to 3 mag in V, or even more.

Having identified a 2MASS counterpart for all our Long Period Variables, we build their $(J - H)$ **vs** $(H - K)$ diagram (see Fig. 8) where we reported also the loci of Late Type Stars as defined by Bessell & Brett (1988) (their Fig. A3). The 2MASS passbands are not exactly those used by Bessell & Brett (1988), but our purpose is just to check an overall consistency and the presence of significant reddenings. In this plot the continuous line at the bottom left is the Main Sequence, which separates around spectral type M0 into a Red Giants (upper) and a Main Sequence (lower) branch. The area enclosed by hatched lines is mostly populated by variable Carbon stars; that enclosed by the continuous line is populated by Oxygen-rich Long Period Variables. To help the reader, we report in this figure also the reddening vector for $E(B-V) = 1$, computed according to Schlegel et al. (1998).

As expected, all our stars are located in or above the area of the Long Period Variables.

Color corrections corresponding to $E(B-V)$ ranging from 1 to 3 mag are required to bring all our stars within the borders of the Oxygen-rich stars locus (continuous line). A discussion of the individual reddening is beyond the purpose of this paper: JHK magnitudes averaged over the full light curve should be necessary, instead of the single snapshots given by the 2MASS catalog.

We searched for a distance estimate of our stars in the Gaia DR2 database (Gaia Collaboration, 2018) as available at CDS: in all cases a matching source with very red $BP-RP$ color was found within 0.35 arcsec from the 2MASS position.

Unfortunately, reliable parallaxes are not available for any of our stars, because the parameters indicating the goodness of the astrometric solution (astrometric_gof_al, astrometric_excess_noise, astrometric_weight_al) are all very poor (Gaia DR2 Documentation, 2019). No parallax accuracy improvements for our stars were given in the EDR3 version (Gaia, 2020). The formal median parallax of our sample is 0.15 mas with nearly symmetric and large spread ($\sigma = 0.59$ mas), many stars having formally negative parallax. The median proper motions of the sample are -2.26 mas/yr in RA and -4.38 mas/yr in Dec, corresponding to -5.0 mas/yr in Galactic longitude and 0.0 mas/yr in Galactic latitude, in fair agreement with the expectations given their positions in the sky.

Assuming the period-absolute K mag relation of Whitelock (2012) and a color excess $E(B-V) = 1$, we get a median distance for the sample of 3.7 kpc, in fair agreement with the expectation. An accurate distance determination for each star would require a knowledge of the individual reddening and of the actual mean K magnitude instead of the 2MASS snapshot value, which is taken at an unknown phase.

6   Conclusions

The large majority of the 150 Long Period Variables in Maffei's M16-M17 sample show a substantially stable period at a distance of 40–50 years. The original classification as Mira or SR is not supported by the extensive work by Soszyński et al. (2013) on the Red Variables in the Galactic bulge, which sets as discriminating parameter a "peak to peak" amplitude $\Delta I_{\mathrm{C}} \leq 0.8$ mag. In this respect nearly all the LPVs of the sample should be considered as Miras, save three (V397 Ser, NSV 10832, and NSV 10772); increasing (somewhat arbitrarily) the limit ΔI_{C} to 1.0 mag brings the potential number of SR to just 8 stars, against 24 of the original classification.

A statistical comparison can be done with the finding by Templeton et al. (2005), who studied 547 Mira or possible Mira (M:) stars from the AAVSO database: none of those stars is included in our sample. In the AAVSO sample, only 3 stars showed a period variation larger than 10%: no surprise that we found no star with a significant period variation in our sample of 150 stars.

Regarding the average magnitudes of the LPVs observed by Maffei, they are well correlated with the OGLE mean magnitudes, with a linear relation of slope nearly 1. However, the spread around this relation is quite large ($\sigma = 0.61\,\mathrm{mag}$), substantially larger than the typical photographic photometry error. It is therefore possible that a few stars have actually changed their mean luminosity by 1 to 2 magnitudes: the most

relevant case, with a ∼4 mag dimming, is KZ Ser.

During this research we found the right identification for 3 misidentified Maffei's variables (NSV 10326 alias M005, NSV 10522 alias M035, and IX Ser alias M179), which will allow their study in the future.

Finally, we point out the reclassification as Mira of five stars in Maffei's sample (GL Ser, NSV 10271, NSV 10326, NSV 10522, NSV 10677), not recognized as such in the original discovery papers.

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