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Populations of AGB stars and LPVs in the Galaxy and Local Group

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Abstract. In this review I will discuss recent developments on the topic of resolved Asymptotic Giant Branch (AGB) stars and Long Period Variables (LPVs) in our Galaxy, the Magellanic Clouds, and the Local Group in general. Since the main characteristics of AGB stars are (1) their infrared, (2) pulsational and (3) chemical properties, it is fitting that I will focus on recent results from the (a) 2MASS/DENIS and MSX near- and mid-IR surveys, the (b) micro-lensing surveys and (c) dedicated narrow-band imaging surveys. The presentation is available at http://www.ster.kuleuven.be/~groen

1. Introduction

All main-sequence stars born with masses below $\lesssim 8\ M_{\odot}$ have or will go through the evolutionary phase called Asymptotic Giant Branch (AGB). The lower limit in initial mass is set by the age of the Galactic Disc, the upper limit is set by the mass where carbon can be ignited in the stellar core. The AGB is the final phase where intermediate-mass stars have nuclear burning in the form of alternate Hydrogen and Helium shell burning, before they cross the Herzsprung-Russell diagram to become Planetary Nebulae and then White Dwarfs.

A summary of the interior structure and stellar evolution up to and on the AGB can be found in the recent textbook "Asymptotic Giant Branch Stars" (Habing & Oloffson 2004).

AGB stars are luminous ([$\sim$0.1 – a few] $10^4\ L_{\odot}$) and cool, with effective temperatures in the range 3850 to $\sim$2500 K (for M0 to M10 giants, e.g. Fluks et al. 1994). From this it follows that AGB stars are big (up to a few hundred $R_{\odot}$), and combining this with the classical pulsation equation[1] $P = Q\ R^{1.5}\ M^{-0.5}$ it follows that any radial pulsations that would occur would have periods between tens and hundreds of days.

Equally important, and typical for the AGB, are the chemical peculiarities that occur during this evolutionary phase (see Chapter 2 in the abovementioned book). Depending in a complex way on initial mass, metallicity, mass-loss, mixing and burning in the envelope [hot bottom-burning], an AGB star may go through several third dredge-up events whereby mainly carbon, nitrogen, oxygen and *s*-process elements are mixed ultimately into the stellar photosphere.

[1] With the pulsation constant Q being of order 0.038.

Depending on the C/O-ratio different molecules form in the cool atmospheres (VO, TiO, C_2, CN) and a star can be classified as M-star (C/O $\lesssim$ 0.95), S-star (0.95 $\lesssim$ C/O $<$ 1.0) or C-star (C/O $\geq$ 1.0). Intermediate classes, MS, SC, also exist. These type of AGB C-stars are also identified with the N-type carbon stars, and they are different from the R-type carbon stars which are likely not on the AGB, and possibly related to a merger of stars on the RGB (see McClure 1997).

The low effective temperatures already make AGB stars redder than all their Main-Sequence progenitors. In addition, the formation of different molecules depending on chemical type makes that the infrared colours of M- and C-stars are different, as will be discussed later.

Furthermore for spectral types later than ~M4-M5 (e.g. Glass & Schultheis 2002) the region close to the star has the right combination of temperature and density for dust grains to form. Dust absorbs efficiently in the optical and radiates in the infra-red. This implies that AGB stars surrounded by dust shells are even redder.

So far, the binary chanel has not been discussed. Main-sequence, sub-giants and giants that have been polluted when a present-day WD was on the AGB and polluted his companion with material enriched in carbon and *s*-process elements. Examples of these classes are the carbon-dwarfs (e.g. Steinhardt & Sasselov 2005), the CH-stars (e.g. Bartkevicius 1996, McClure & Woodsworth 1990), the Barium stars (e.g. Jorissen et al. 1998) and the "extrinsic" S-stars (e.g. Van Eck & Jorissen, 1999). Recently, it has become clear that about 20% of Carbon-enhanced Extreme Metal-Poor (CEMP) stars are binaries and show s-process enhancements (Lucatello et al. 2005). These classes will not be discussed further here.

Based on the main properties of AGB stars mentioned above, the following recent results will be discussed: 2MASS/DENIS and MSX in connection with the infrared colours, the result of the micro-lensing surveys in connection with variability, and the results of dedicated narrow-band surveys in connection with the chemical characteristics of AGB stars.

2. AGB stars in the 2MASS/DENIS and MSX surveys

2.1. 2 Micron All Sky Survey – DEep Near-Infrared Survey

In May 2003 the DENIS team released their second data release containing IJK photometry for 195 million point sources in the southern sky down to K = 14.0 (available at VIZIER at http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=B/denis)

In March 2003 the final *all-sky* 2MASS JHK-database was released containing 470 million point sources down to a typical limiting magnitude of K = 14.3 (Cutri et al. 2003). This implies that a typical carbon star *even with no mass loss* and with a luminosity of 7000 $L_\odot$ and effective temperature of 2650 K can be viewed to 150 kpc, and mass-losing AGB stars to even larger distances.

This suggests that AGB stars in many Local Group galaxies have been detected by 2MASS. Groenewegen (2005) presents a list of almost 100 candidates in 16 Local Group (LG) galaxies (excluding the Magellanic Clouds, M31,

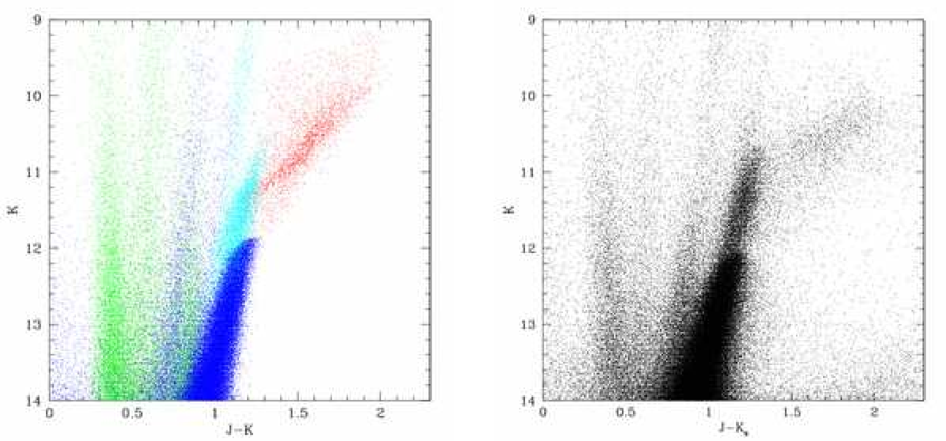

Figure 1. From Marigo et al. (2003; their figure 12). Left panel: Simulated CMD based on TP-AGB tracks with variable molecular opacities (i.e. Marigo 2002), assuming an half-and-half mixture of fundamental-mode and first-overtone pulsators for the stars which evolve into the C-star phase. C-stars are marked in red and O-rich low-mass TP-AGB stars in cyan. Green is foreground, and dark blue are RGB stars. Right panel: The same diagram for the selected 2MASS data. Note the good correspondence between the different featured in the CMD.

M33), selected on $(J-K)$-colour and K-magnitude. We hope to confirm the 34 candidates in Fornax dSph by NIR spectroscopy in the fall of 2005 using the VLT.

In the near future much deeper NIR survey data of LG galaxies is within reach of wide-field imaging facilities as UKIDSS (http://www.ukidss.org) and VISTA (http://www.vista.ac.uk).

Up to now, the 2MASS and DENIS data have extensively been used to study AGB stars in the Magellanic Clouds:

- Weinberg & Nikolaev (2001) who select stars with $9.5 \lesssim K \lesssim 11.5$ and $1.4 \lesssim (J-K) < 2$ (assumed to be C-rich LPVs) to study the 3D structure.

- Cioni & Habing (2003) present results on the C/M ratio across the face of the SMC and LMC (results on NGC 6822 are presented in Cioni & Habing, 2005) using DENIS data. Carbon and O-rich AGB stars are selected from the $(I-J)-(J-K)$ colour-colour (CC)-diagram. The C/M ratio is then determined in 100×100 cells of 0.04 square degrees. In the SMC there is no clear trend with position while in the LMC the ratio appears to decrease radially. Overall the distribution is clumpy and corresponds to a spread in metallicity of 0.75 dex.

- Marigo et al. (2003; see Figure 3) fit the colour-magnitude diagram (CMD) of 2MASS objects within 4 degrees of the bar optical centre using a population synthesis code (Girardi et al. 2005), with special emphasis on the tail of carbon stars. She demonstrates the importance of including the change in molecular opacities in evolutionary calculations as stars evolve from O-rich to C-rich (Marigo 2002).

Regarding our own Milky-Way it is interesting to mention the Faint High-Latitude Carbon (FHLC) stars[2]. Originally one was interested in identifying carbon stars at high galactic latitude as tracers of the halo. However, quite a few turned out to have a measurable parallax or proper motion, indicating that these were not giants, but rather carbon dwarfs. Papers that use 2MASS data in connection with FHLC stars are:

- Liebert et al. (2000) looked for very red objects in the halo in the 2MASS second incremental data release and confirmed, taking optical spectra, four new halo carbon stars with $(J-K)$ between 2.3 and 4.7. These stars are similar to two examples found earlier using IRAS (e.g. Groenewegen et al., 1997, and references therein).
- Mauron et al. (2004) did a similar study using the 2MASS but their initial selection was based on $(H-K) > 0.4$ and $(J-H) > 0.95$, hence significantly bluer than the stars found by Liebert et al., but not as blue as some carbon dwarfs. Their initial sample of about 1200 objects was trimmed by eliminating known objects using SIMBAD and stars with $(B-R) < 1.5$ from the USNO. They ended up with a list of ∼200 best candidates and optical spectra were taken of 97 and 30 were confirmed as carbon stars.
- Downes et al. (2004) follow up on the work by Margon et al. (2002) by selecting FHLC stars using 5-colour Sloan Digital Sky Survey (SDSS) photometry, and then taking optical spectra. Correlation with the 2MASS is done to provide the IR magnitudes. Margon et al. find 39, and Downes et al. 251 FHLC stars. At least half of these are dwarf carbon stars. The density of FHLC stars is about 0.06 per square degree down to $r^* = 21$.

2.2. Midcourse Space Experiment

The *Midcourse Space Experiment* (MSX; see Price et al. 2001) satellite mission included the SPIRIT III instrument that obtained mid-IR data in 6 bands designated A,B1,B2,C,D,E with central wavelengths between 8 and 21 μm. Band A was the most sensitive one with a limiting flux-density of order 0.1 Jy, and most of the 320 000 objects are only detected in this band.

MSX observed the Galactic plane ($\mid b \mid < 5°$) and the LMC. Lumsden et al. (2002) and Ortiz et al. (2005) investigate the colours of AGB stars. Both papers reach similar conclusions in that the combination of MSX magnitudes with near-infrared magnitudes (J or K) is a powerful diagnostic in discriminating between different types of reddened sources.

The MSX results on the LMC are discussed in Egan et al. (2001). 1806 sources were detected in the A band of which 1664 had positional matches with 2MASS. This allowed them to discriminate different classes of objects in a $(J-K)$-$(K-A)$ CC-diagram.

[2]The halo usually defined as $\mid b \mid \gtrsim 30$ degrees in this context.

Table 1. Red variables from micro-lensing surveys

Reference	Area	Number	survey data
Wood et al. 1999 &			
Wood 2000	0.25 $\square^2$ LMC-bar	1430 RV$^{(1)}$	MACHO + IR
Cioni et al. 2001	0.5 $\square^2$ LMC-OC	240 M+SR	EROS + D$^{(2)}$
Noda et al. 2002	14 $\square^2$ LMC	146 LPV	MOA + D
Lebzelter et al. 2002	0.25 $\square^2$ LMC-bar	470 RV	AGAPEROS + D
Cioni et al. 2003	0.25 $\square^2$ SMC	458 RV$^{(4)}$	MACHO+D/2M$^{(3)}$
Ita et al. 2004a,b	3 $\square^2$ LMC-centre	~9000 RV	OGLE + SIRIUS
	1 $\square^2$ SMC-centre	~3000 RV	OGLE + SIRIUS
Kiss & Bedding 2003	4.5 $\square^2$ LMC-centre	~23000 RV	OGLE + 2M
			with $J-K>0.9$
Kiss & Bedding 2004	2.5 $\square^2$ SMC-centre	~3200 RV	OGLE + 2M
			with $J-K>0.9$
Groenewegen 2004	SMC+LMC	2277 SC$^{(5)}$	OGLE + D/2M
Soszynski et al. 2004	SMC+LMC	18 000 SARV$^{(6)}$	OGLE
Noda et al. 2004	LMC	4000 RV	MOA + D
Fraser et al. 2005	LMC	22 0000 RV	MACHO + 2M
Raimondo et al. 2005	SMC	1080 C-stars	MACHO + 2M/D
Alard et al. 2001	GB (NGC6522+Sgr I)	332	MACHO+ IG$^{(7)}$
Glass & Schultheis 2002	GB (NGC6522)	174 M-giants	MACHO+D+IG
Glass & Schultheis 2003	GB (NGC6522)	1085 RV	MACHO + D
Wray et al. 2004	GB	13 000 SARV	33 OGLE-fields
GB05	GB	2691 Miras	OGLE + D/2M

(1) RV = red variables. (2) D = DENIS IJK survey. (3) 2M = 2MASS JHK survey. (4) A pre-selected sample of stars detected in an ISOCAM survey (Loup et al., in prep.). (5) SC = Spectroscopically Confirmed stars. (6) SARV = small-amplitude red variables. (7) IG= ISOGAL mid-IR survey.

3. Long Period Variables in the micro-lensing surveys

Before focusing on the results of the micro-lensing surveys *per se* on LPV research, it is worthwhile to mention a few variability surveys that also are in the process of providing results on variable stars. Contrary to the micro-lensing surveys the surveys mentioned below will be most useful for studies of variable stars in the solar neighbourhood and a welcome complement to the classical General Catalog of Variable Stars (GCVS, Kholopov et al., 1998) which lists 7200 Mira variables. These new surveys are:

- ASAS (All-Sky Automated Survey), see Pojmanski (2002).

  This survey monitored about 15 million stars in the magnitude range $V = 5-14$, south of declination +28 degrees, for 3 years every 1-3 days.

  Of the 38 000 variables in the ASAS-3 release 2551 are classified as Mira variables on the web-site.

- NSVS (Northern Sky Variability Survey), see Woźniak et al. (2004a).

  This survey monitored about 14 million objects in the northern sky (and some fields with less quality down to -38 in declination), in the optical

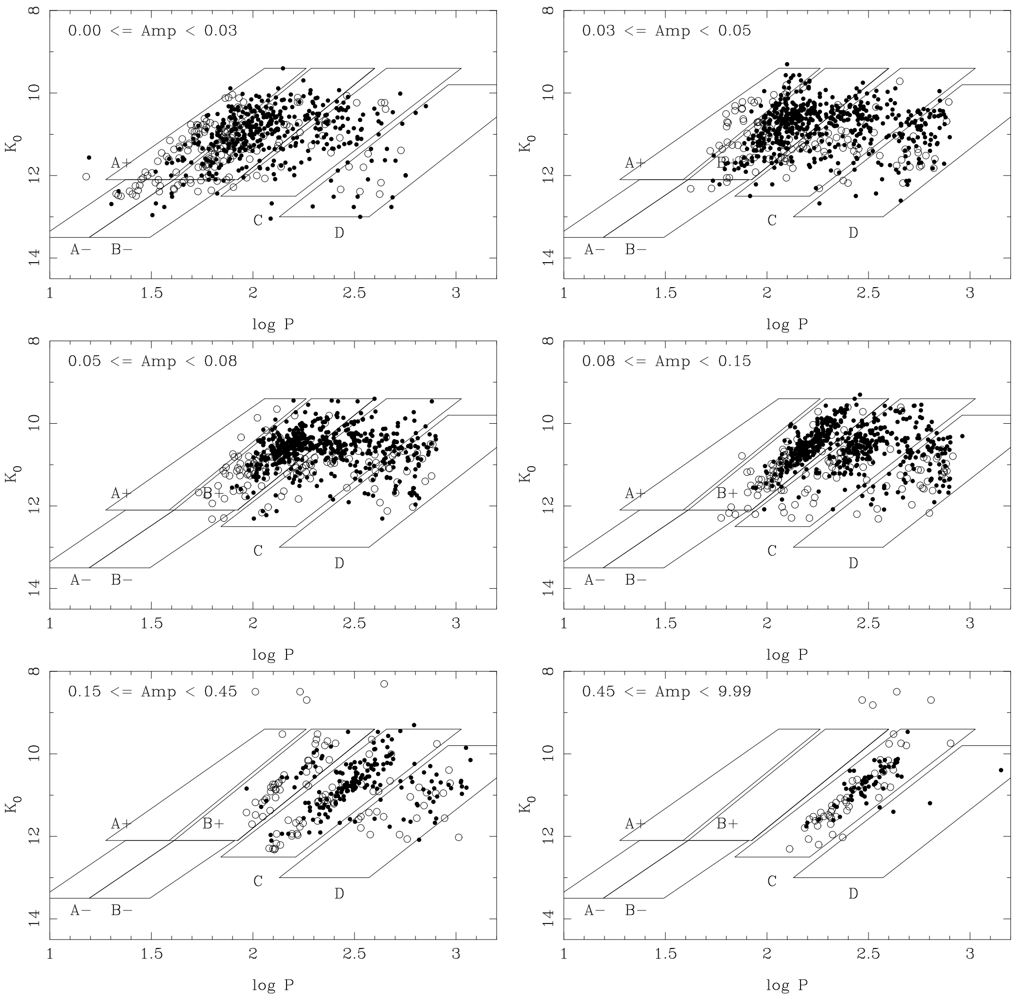

Figure 2. K-band PL-relation for the LMC. Panels indicate selection on I-band amplitude as indicated in the upper left corners. Carbon stars are indicated by filled circles, M- and S-stars by open circles. Boxes related to the "ABCD" sequences are indicated. From Groenewegen (2004).

magnitude range 8 to 15.5, over a 1 year baseline with 100-500 measurements per object.

Woźniak et al. (2004b) use this dataset to create a catalog of 8600 variable AGB stars.

- TAROT (Klotz, this proceedings)

3.1. The Magellanic Clouds

Lets us now turn to the micro-lensing surveys. After the initial results presented by Wood et al. (1999) and Wood (2000) on a single field of MACHO data in the LMC, there has been a flood of papers on this topic. Table 1 summarises

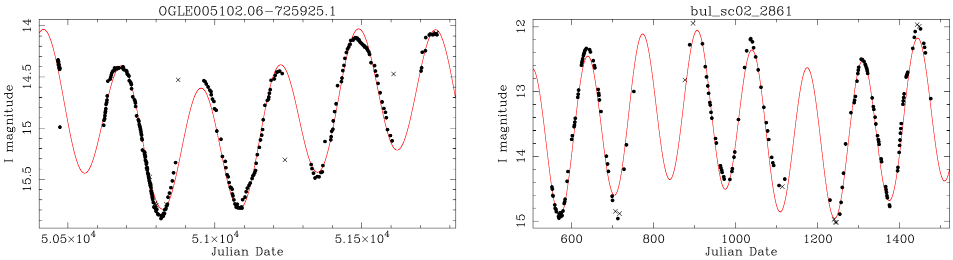

Figure 3. Example of LPVs with multiple periods one of which is in Box D. In the left panel an LPV from the SMC with periods of 267 and 1300 days (from Groenewegen 2004), in the right panel an example from the Galactic Bulge with periods of 134 and 700 days (from Groenewegen & Blommaert, 2005).

the current state of affaires. The main differences are in the location of the sky (SMC, LMC, Galactic Bulge), the variability survey used (MACHO, OGLE, MOA, EROS), use of infra-red data (publicly available 2MASS or DENIS data, or own observations), and the selection of the variables (unbiased, selection of Miras, starting from spectroscopically known AGB stars).

The main results are very similar between these papers, and one of the main results is shown in Figure 2. It shows different sequences labelled "ABCD". Sequences A and B are further split-up relative to the tip of the RGB. Sequence B is now often considered to be actually 2 sequences (e.g. Soszynski et al., 2004, Fraser et al., 2005).

Selecting on amplitude selects stars in different boxes. Selecting the largest amplitudes results in a nice Period-Luminosity relation in Box C that can be identified with the classical Mira variables. They are almost certainly pulsating in the fundamental mode (Wood 1999, 2000, Fraser et al. 2005). Selecting progressively smaller amplitude cuts populates more and more Box B and then A. These stars are thought to be overtone pulsators (1st, 2nd, 3rd) although theoretical PL-relation do not fit the observed sequences exactly (e.g Fraser et al. 2005).

The big surprise to come out of these observations was sequence D. Stars with a period in this box have multiple periods with the shorter period in one of the other boxes. Examples of the light curves are shown in Figure 3. The origin of these, so-called, Long Secondary Periods (LSPs) is still a mystery. Several explanations have been proposed, g^+ non-radial modes, binary companions, rotating prolate spheroids, episodic dust ejection, star spot cycles, but none is satisfactory (Olivier & Wood 2003, Wood et al. 2004).

3.2. The Galactic Bulge

Table 1 includes the few works that have used the results of the micro-lensing surveys to study variables in the direction of the Galactic Bulge (GB). They extend previous classical works on Bulge variable stars, like those of Lloyd Evans (1976), Glass & Feast (1982), Whitelock et al. (1991), Glass et al. (1995), Alard et al. (1996) and Glass et al. (2001).

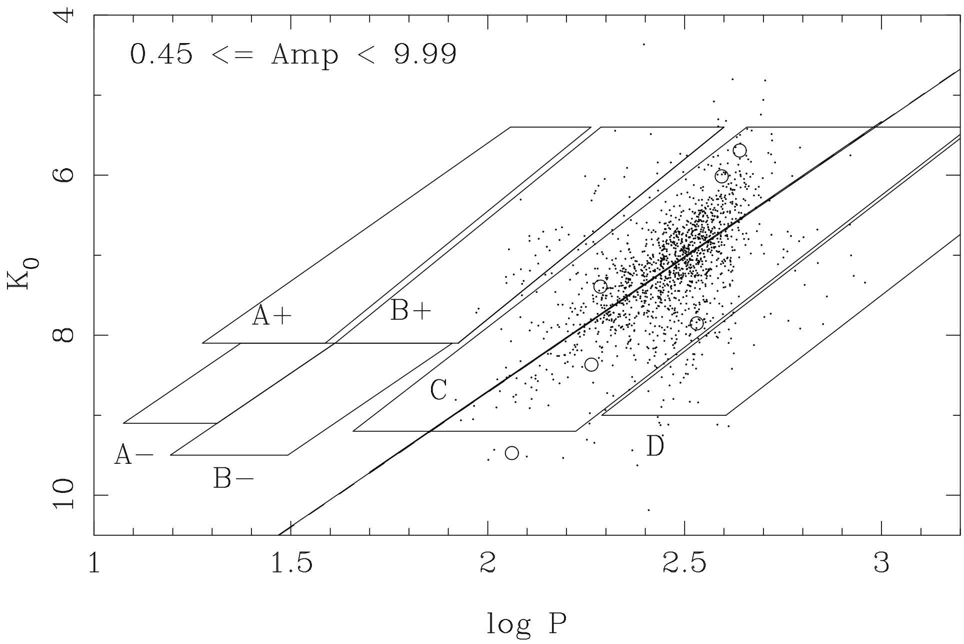

Figure 4. K-band PL-relation in the direction of the Galactic Bulge for periods with an I-band amplitude larger than 0.45 mag and $(J-K)_0 < 2.0$. Known M-stars are indicated by open circles. The line indicates the PL-relation: $m_{\rm K} = -3.37 \log P + (15.47 \pm 0.03)$. From Groenewegen & Blommaert (2005).

The work by Groenewegen & Blommaert (2005, GB05) appears to be the first paper to use the full OGLE-II database to study classical Mira variables (I-band semi-amplitude larger than 0.45 magnitudes), and some details of this study are presented here.

Figure 4 presents the K-band PL-relation for the 2691 Mira variables identified in the OGLE database after correlation with the 2MASS and DENIS. The mean PL-relation is also shown.

With this slope fixed, one can now determine the zero point (ZP) of the PL-relation for each OGLE field separately. In Figure 5 the ZP is plotted against Galactic longitude for the inner OGLE fields. There is a significant slope indicating the presence of the well-known bar.

Simulations have been carried out using the basic disk & bulge model of Binney et al. (1997), with the main parameter being the angle between the major axis of the bar and the line-of-sight towards the Galactic Centre. It turns out that for angles of 43 and 79 degrees one can account for the observed slope in Figure 5, but only the model with an angle of 43 degrees can also account for the observed number of stars.

The preferred value of $\phi = 43°$ is in agreement with the values of about 45° by Whitelock (1992), based on 104 IRAS detected Mira variables, and the preferred value of 46 degrees by Sevenster et al. (1999), based on an analysis of OH/IR stars in the inner Galaxy.

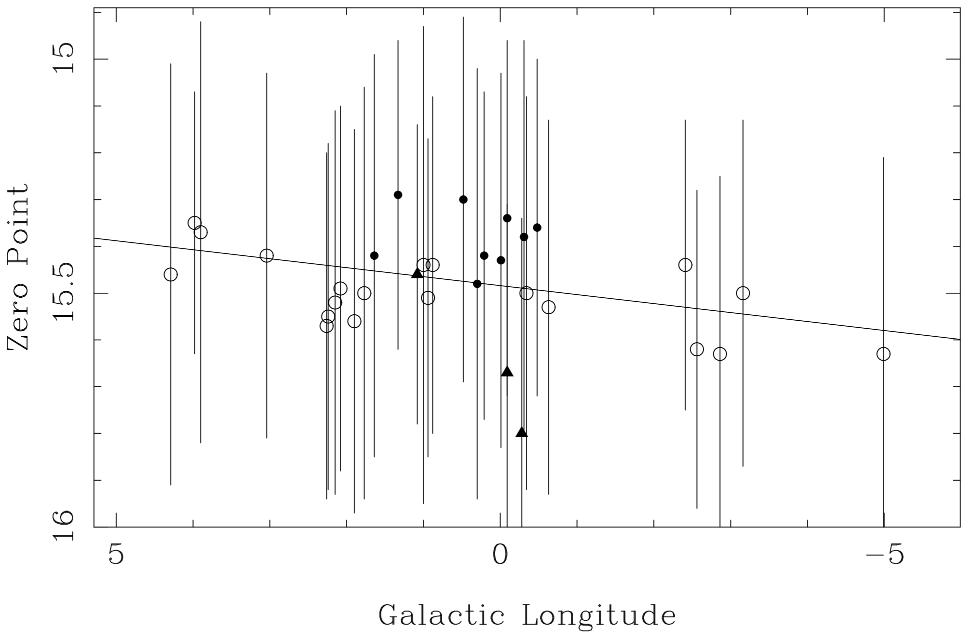

Figure 5. Zero point of the Mira K-band PL-relation in the Galactic Bulge as a function of longitude for the inner fields with $| l |< 5$ degrees. Galactic latitudes below $-4.0°$ are indicated by filled triangles, those larger than $-2.6°$ by filled circles, and the remaining by open circles. Error bars are also plotted. The line represents a linear least-squares fit.

Other values in the literature are usually much larger, between 60 and 80 degrees: Dwek et al. (1995) and Binney et al. (1997), based on COBE-DIRBE data, Stanek et al. (1997), based on bulge red clump stars, Robin et al. (2003) and Picaud & Robin, based on colour-magnitude fitting. Sevenster et al. (1999), however, argues that these values are commonly found when no velocity data is available, the longitude range is too narrow or when low latitudes are excluded. It is also possible that these studies are tracing other populations, which may be differently distributed than the Miras. Whitelock et al. and Sevenster et al. do use populations closely related to the Mira stars and find an angle of the bar close to the one we derive.

Another way to look at this dataset is shown in Figure 6 where the period distribution is shown for OGLE-fields at similar latitudes but different latitudes. 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 $K \sim 12.0$.

A Kolmogorov-Smirnov test indicates that the fields at $-1.2°$ and lower are statistically identical, and very different from the inner field, where a tail of longer periods is observed.

To quantify the nature of the Mira Bulge population, synthetic AGB evolutionary models have been calculated. In brief, the synthetic AGB code of

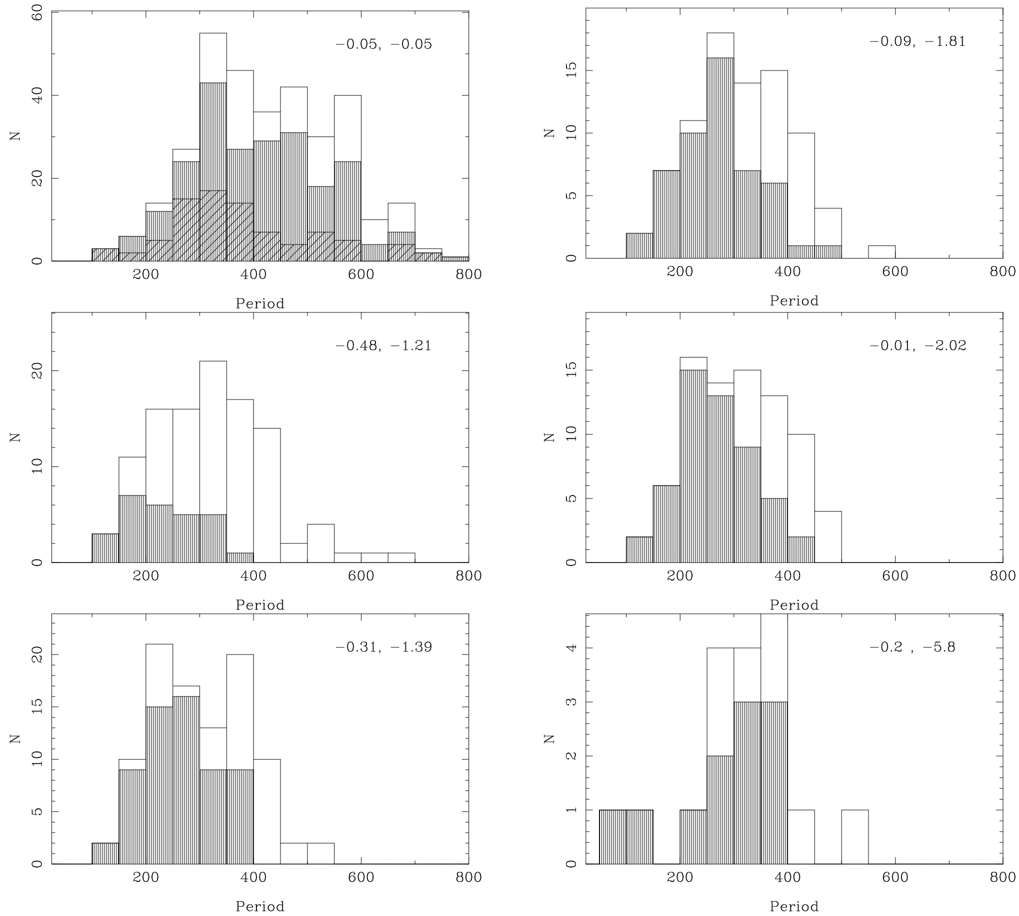

Figure 6. Galactic Bulge Mira period distribution for 6 fields with similar longitudes but a range in latitudes (as indicated in the top right corner). For the field at $b \sim -5.8$ degree, OGLE fields 6 and 7 have been combined. For the shaded histograms only stars with $(J-K)_0 < 2.0$ have been included. 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. From Groenewegen & Blommaert (2005).

Wagenhuber & Groenewegen (1998) was finetuned to reproduce the models of Vassiliadis & Wood (1993) for $Z = 0.016$ 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. The results are shown in Figure 7.

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. To explain the excess

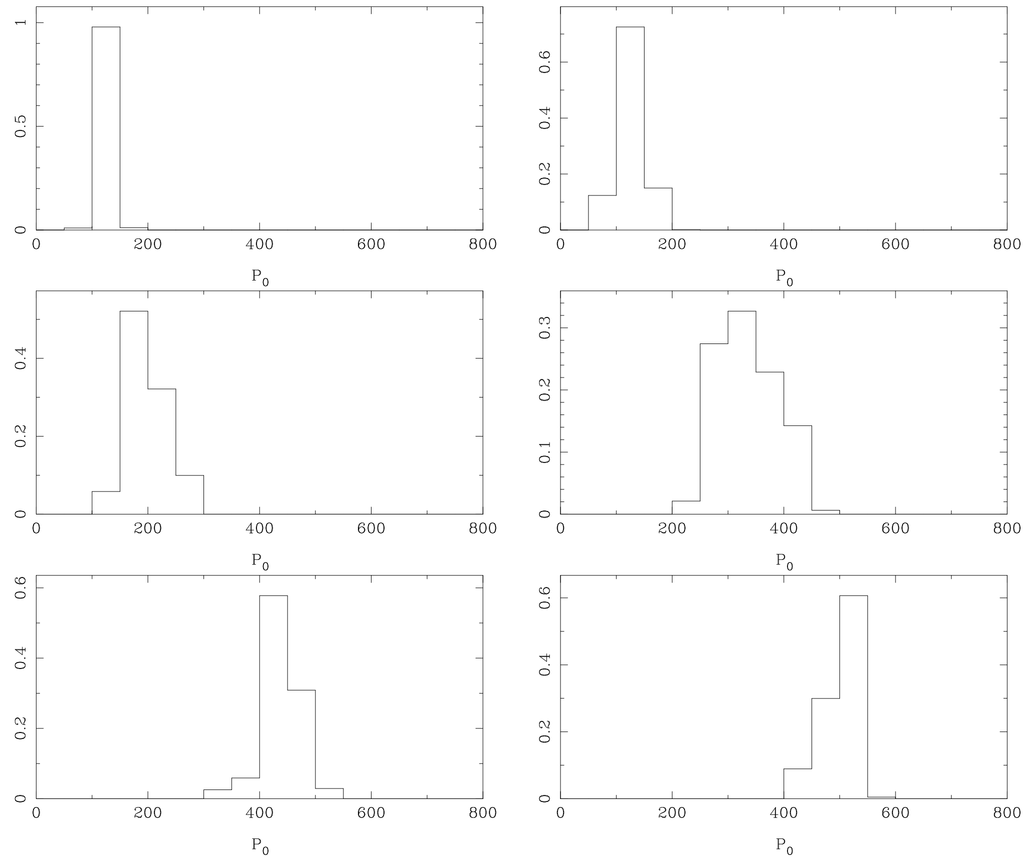

Figure 7. Theoretical period distribution of optically visible stars inside the observed instability strip for masses 1.1, 1.2, 1.5, 2.0, 2.5, 3.0 $M_{\odot}$ (left to right, top to bottom).

periods in the range of 350-600 days observed 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.

The formation history of the Bulge is still a matter of debate. In several works like in Kuijken & Rich (2002) and recently in Zoccali et al. (2003), the bulge is considered to be old (> 10 Gyr) and formed on a relatively short timescale (< 1 Gyr) (e.g. Ferreras et al. 2003). The bulge Miras do not fit in this picture as, according to the analysis in GB05, they are considerably younger.

Their results agree more with the analysis of the infrared ISOGAL survey discussed in van Loon et al. (2003). They conclude that the bulk of the bulge population is old (more than 7 Gyr) but that a fraction of the stars is of intermediate age (1 to several Gyr). The Miras in GB05 study can thus be considered as the intermediate age population seen in their analysis.

If indeed the bulk of the bulge population is old and formed quickly and if the Miras are of intermediate age, then the Miras must be representatives of a population which was added at a later stage and it is unclear how it relates to the overall bulge. An interesting scenario suggested in Kormendy & Kennicutt (2004) is the one in which a secondary bulge or also called pseudo-bulge forms within an old bulge. Such a process would be connected to the presence of a "bar" which would add "disky" material into the old classical bulge. The Miras are indeed situated in a bar-structure as was discussed earlier.

4. AGB stars in the Local Group using narrow-band filter surveys

This technique uses the specific characteristic of late-type M-stars, where strong TiO bands develop, and C-stars, with C_2 and CN molecular bands. First introduced by Palmer & Wing (1982) and then applied by Richer et al. (1984) and Aaronson et al. (1984) the method typically uses two broad-band filters from the set V, R, I, and two narrow-band filters near 7800 and 8100 Å, which are centred on a CN-band in carbon stars (and near-continuum in oxygen-rich stars), and a TiO band in oxygen-rich stars (and continuum in C-stars), respectively. In an [78-81] versus $[V-I]$ (or $[R-I]$) colour-colour plot, carbon stars and late-type oxygen-rich stars clearly separate redwards of $(V-I) \approx 1.6$. For an illustration of this, see Cook & Aaronson (1989) or Nowotny & Kerschbaum (2002).

Originally, the applications were limited mainly because of the small format CCDs and the use of relatively small telescopes. However the last about 5 years have seen a remarkable revival through the use of these narrow-band filters using wide-field imagers on bigger telescopes (2-4m class).

At present a large fraction of LG galaxies have been surveyed, at least partially, using these narrow-band filters. For recent reviews see Azzopardi (1999) and Groenewegen (1999, 2002, 2005). The most recent works not listed in these reviews are the surveys by:

- Kerschbaum et al. (2004) who surveyed a $6.5' \times 6.5'$ field covering almost all of And II and identifying 7 C-stars.
- Demers et al. (2004) who identified 676 carbon stars in a $42' \times 28'$ field centered on IC10.
- Battinelli & Demers (2005a) who surveyed a 450 arcmin^2 field about 40 kpc along the southern major axis of M31 finding only a handfull of C-stars, concluding they reached the edge of the M31 disk, at least as defined by an intermediate age population.
- Harbeck et al. (2005) who found one candidate carbon star in And IX.
- Rowe et al. (2005) who surveyed a $74' \times 56'$ field centered on M33 finding 7936 C-stars.

A quantitative theoretical interpretation or understanding of this data is clearly lacking. At the lowest level of interpretation these data indicate a relation between the ratio of C-to-M stars and (mean) metallicity in the Galaxy, as shown in Figure 8 (data from Battinelli & Demers, 2005b).

Mouhcine & Lançon (2003, see Figure 9) present evolutionary population synthesis models, including chemical evolution, with special focus on intermediate age populations. Their models are the first that are able to account qualitatively for the observed trend in Figure 8 adopting 'typical' Star Formation

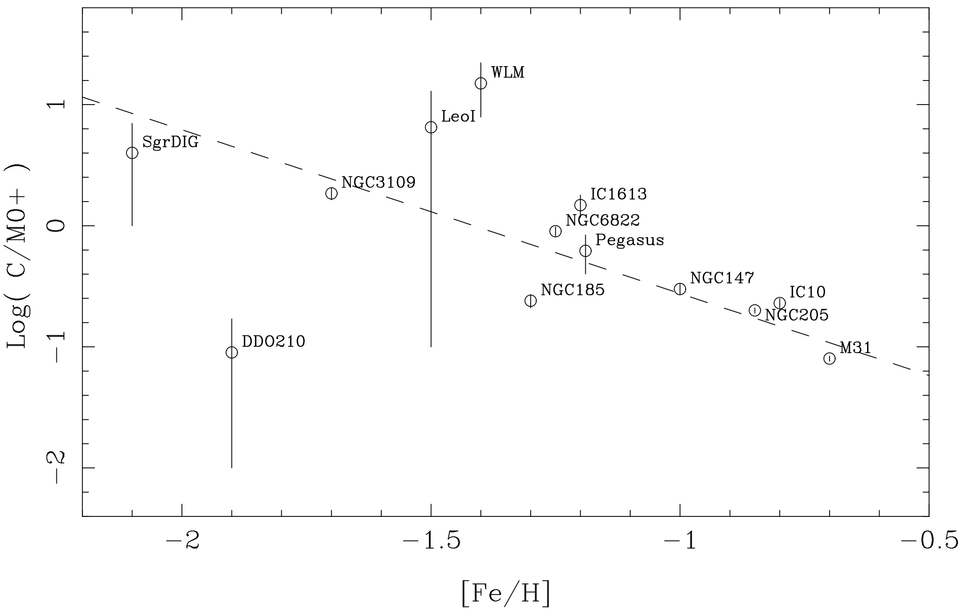

Figure 8. Log (number Carbon stars / number M0+ -stars) versus metallicity. Data taken from Battinelli & Demers (2005b). The line is a weighted least-squares fit to the data:
log (C/M0+) = (-1.35 ± 0.20) [Fe/H] + (-1.92 ± 0.20).

Histories (SFHs) for Sa, Sb, Sc and Irr Hubble type galaxies. The AGB phase is included through a semi-analytical treatment of the third dredge-up, with efficiency parameters set to values that have been determined in other studies to fit the LMC carbon star LF and C/M ratio.

With SFH now (becoming) available for most LG galaxies (see Dolphin, this proceedings) one could investigate for individual galaxies whether these SFHs predict the observed number of M- and C-type AGB stars. Repeating this for a large set of galaxies covering a range of metallicities would possible better constrain individual SFHs for intermediate ages, as well lead to a comprehensive picture of dredge-up and mass loss efficiency as a function of metallicity in AGB stars.

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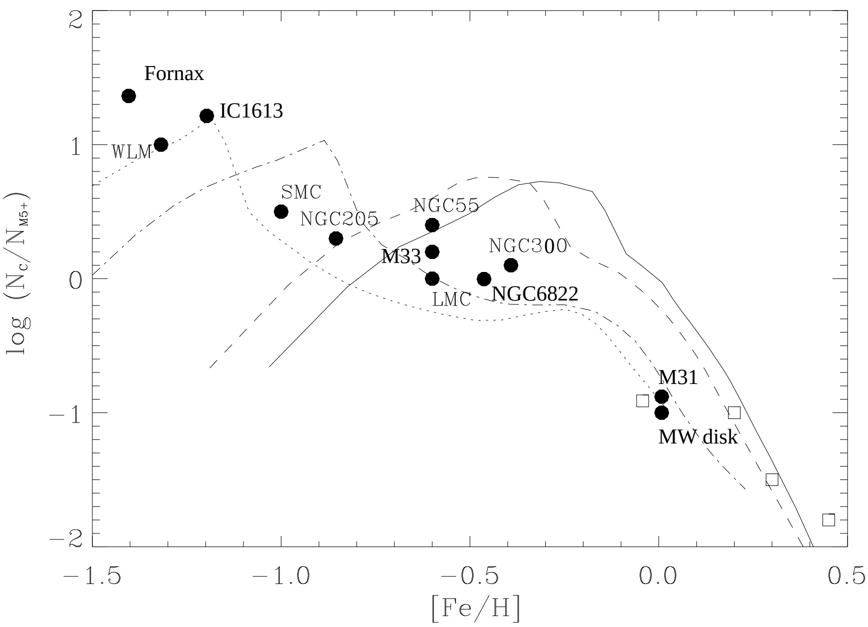

Figure 9. Figure 8 from Mouhcine & Lançon (2003) showing Log (number Carbon stars / number M5+ -stars) versus metallicity using data points from Groenewegen (1999). Lines indicate model predictions assuming typical SFRs, characteristic of Sa (solid), Sb (sahed), Sc (dot-dash) and Irr (dotted) type galaxies.

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