MASS-LOSING AND PULSATING AGB STARS IN THE MAGELLANIC CLOUDS

Martin Groenewegen

Instituut voor Sterrenkunde, Celestijnenlaan 200B, B-3001 Leuven, Belgium

groen@ster.kuleuven.ac.be

Abstract

I present some new results on mass-losing and pulsating stars in the LMC and SMC, based on an analysis of OGLE/MACHO light curves and DENIS/2MASS/ISO infrared data, for samples of AGB stars detected by IRAS, and by the recent ISOCAM "minisurvey" of the SMC.

The conclusions are that (1) the scatter in the PL-relation at long periods is (much) larger than that for $P < 400$ days, (2) the SEDs of some carbon stars are not well fitted in the blue, indicating possibly some missing opacity problem in the model atmospheres, or that the effective temperatures are below 2600 K, the lowest temperature in the available model grid, and (3) the period-mass loss rate relation for C-rich SMC stars seems to follow that derived for Galactic carbon-rich Miras, suggesting no explicit dependence of mass loss rate on metallicity.

Keywords: Stars: AGB and post-AGB, Stars: mass-loss, Magellanic Clouds

Introduction

The mass-loss phenomenon in cool stars manifests itself most clearly through infrared emission. Although ground-based near-infrared (NIR) observations of Asymptotic Giant Branch (AGB) in the Magellanic Clouds (MCs) exist in the literature of the 1980s, they are mostly of individual objects (since observations at that time were obtained with single-channel photometers) and are not very deep. The realisation that "obscured" stars, that is stars with a very high mass loss rates that are faint or invisible in the optical, were in fact detected in the IRAS survey (Whitelock et al. 1989, Reid et al. 1990, Loup et al. 1997), has sparked a lot of follow-up observations on these IRAS detected AGB stars, ranging from single-epoch NIR observations (Reid 1991, Zijlstra et al. 1996, van Loon et al. 1997, 1998, Groenewegen & Blommaert 1998), NIR monitoring (Wood et al. 1992; Wood 1998; Whitelock, this proc.), and later on, follow-up ISO observations (Trams et al. 1999; Blommaert et al. 2002, in preparation) in the mid-IR.

However, the sample of IRAS detected AGB stars in the MCs is in many ways biased, as it represents a sample of AGB stars with the highest mass loss rates and/or objects that were close to maximum light in their pulsation cycle, as the observed IRAS fluxes were very close to the IRAS detection limit.

In recent years, the DENIS (Cioni et al. 2000), and 2MASS surveys have made it possibly to study red AGB stars in the MCs in a way that is less biased. The same will be possible soon using the data obtained with a small unbiased survey of the MCs with the ISOCAM instrument (Loup et al. 2002, in preparation).

Naturally, long-period variables are long known to exist in the Magellanic Clouds (MCs) (e.g. Payne-Gaposhkin 1971). Large numbers of Semi-Regular and Mira variables have been identified by comparing Schmidt plates over a several epochs (e.g. Hughes 1989, Reid et al. 1995, and references therein).

In recent years the surveys searching for micro-lensing events (MACHO, EROS, OGLE, MOA) have resulted in the detection of innumerable variable objects, many of which are long-period variables. Wood et al. (1999) and Wood (2000), using MACHO (see also Wood in these proceedings), and confirmed by Cioni et al. (2001), using EROS data, have shown that in a magnitude - period diagram (at least) 5 sequences can be identified, four of which seem to be indisputably related to the Mira variables, pulsating in the fundamental mode, and semi-regular variables pulsating in the fundamental, first, second and third overtone mode.

In the present paper, I take data from the recently available mircolensing and IR surveys to discuss some aspects of variable stars in the MCs.

1. The samples and results

The following samples of stars have been considered. Firstly, all (as far as I am aware off) 19 AGB stars detected by IRAS in the LMC, with known pulsation periods (from Wood et al. 1992, Wood 1998, and some preliminary results dated 1998 from the now finalised IR monitoring observations of LMC AGB stars discussed by Whitelock during this proceedings), as I previously discussed in Groenewegen et al. (2000). For these stars ISO data was gathered from Trams et al. (1999). As

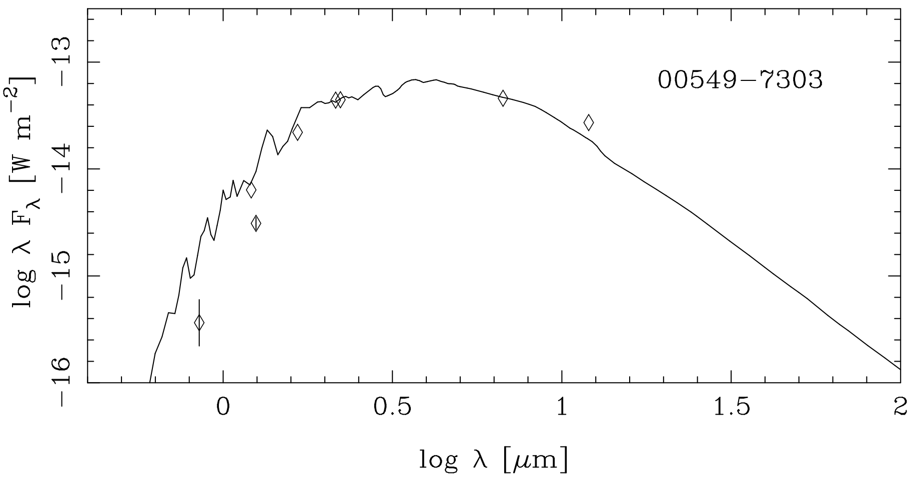

Figure 1. Fit to the SED of a star using amorphous carbon dust and a carbon star model atmosphere. Parameters are L= 13 700 $L_\odot$, $\dot{M}$= 2.8 $\cdot 10^{-6}$ $M_\odot yr^{-1}$. Note the lack of agreement in the optical.

pulsation periods are already available, no search in the OGLE or MACHO database was made for this sample.

The second sample considers the AGB stars detected by IRAS in the SMC as discussed by Groenewegen & Blommaert (1998). ISO observations (mostly 12 and 25 μm data, and some CAM-CVF spectra) have been obtained for a large subset of these stars (Blommaert et al. 2002). The ground-based IR positions of the stars have been correlated with the DENIS (Cioni et al. 2000) and 2MASS database, in order to obtain improved positions and IJK and/or JHK photometry. The improved position or the ground-based IR position was then correlated with the OGLE and MACHO databases. In many cases there was no match as the stars are too red to have been detected in the optical. Sometimes there was more than one match within a few arcsec, and then it was checked which source showed long period, large amplitude behaviour. Seven objects of this sample of 28 have an counterpart in OGLE and/or MACHO.

The third sample considered contains a selected sub-sample of 15 objects of the over 1000 objects detected in the ISOCAM "minisurvey" of the SMC (Loup et al. 2002), with well determined ISOCAM fluxes and with DENIS and 2MASS counterparts. Ten of these have an counterpart in OGLE and/or MACHO.

The OGLE and MACHO light curves were downloaded, and analysed with the interactive program Period98 (Sperl 1996). Basically, a Fourier

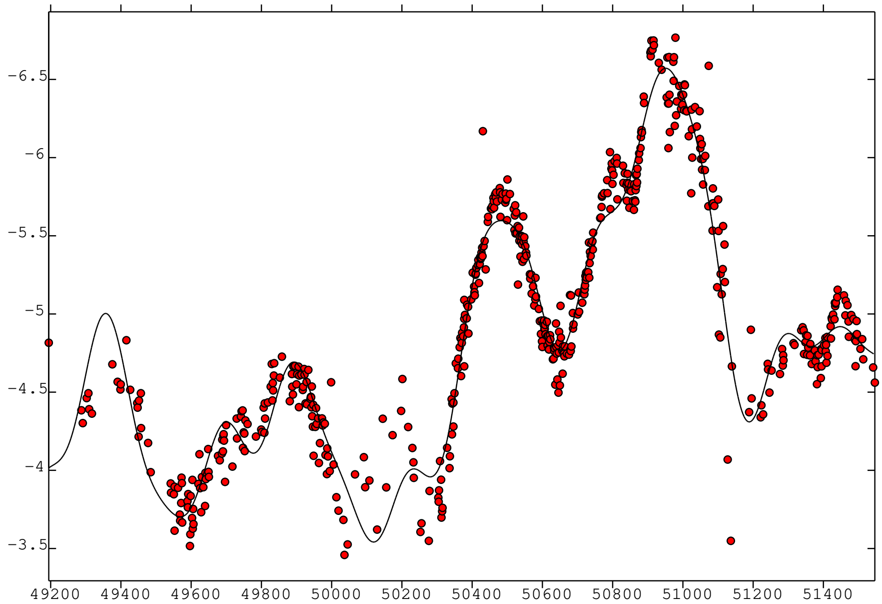

Figure 2. MACHO Red-channel light curve of the object in Fig. 1. MACHO Red-channel magnitude is plotted versus Julian date.

analysis is performed on the data and estimates of the frequency with the most power, and the amplitude are returned. Then, a sinusoidal fit is made to the data. A Fourier analysis can then be performed on the residuals, and so on, until no significant decrease in the rms is obtained.

The IR (2MASS, DENIS and previous single-epoch or monitoring) data, IRAS and ISO results are gathered to construct the Spectral Energy Distributions (SEDs). The SEDs are fitted with a dust radiative transfer code (Groenewegen 1993), basically to derive luminosity and total mass loss rate. In all calculations a gas-to-dust ratio of 200, an expansion velocity 10 km/s, and distances to the LMC and SMC of respectively 50 and 63 kpc are assumed. The central stars are represented by model atmospheres of M-stars (Fluks et al. 1994), or carbon stars (Loidl et al. 2001). The type of dust is either silicate or amorphous carbon dust, respectively. In most cases the chemical type of the object is not known. However, the thermal emission of carbon and silicate dust are so different, that, in many cases, a good fit to the SED is only obtained for one type of dust.

Figures 1-3 give examples of a fit to the SED, and the MACHO and OGLE light curves for the same object. The fit is good at longer wave-

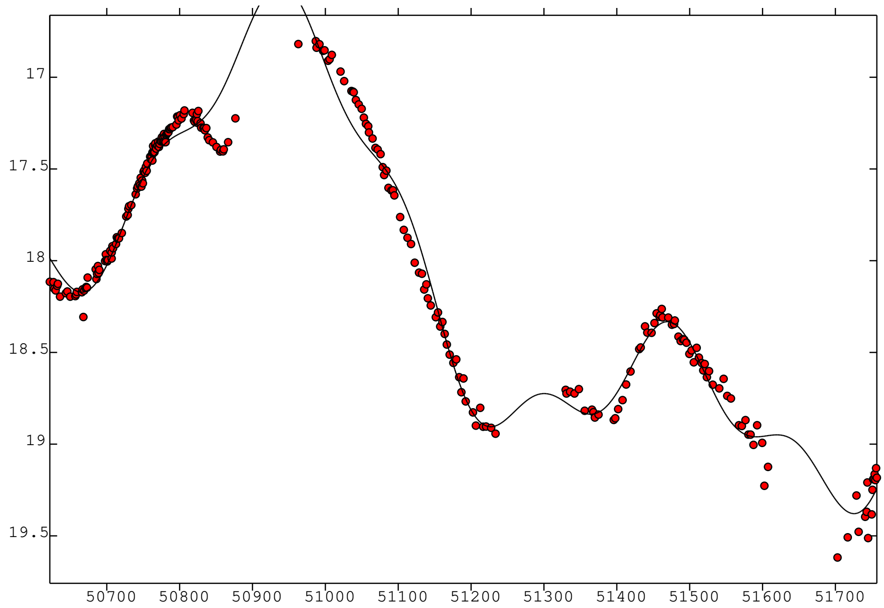

Figure 3. OGLE I-band light curve of the object in Fig. 1. The I-magnitude is plotted versus Julian date. Note the good correspondence in the shape of the light curve compared to Fig. 2.

lengths but poor short ward of 1 μm. Although the example presented is extreme, I often found a disagreement in the optical between data and model, possibly indicating a missing opacity problem in the carbon star model atmospheres, or, simply, that the effective temperatures of the carbon stars in the sample are generally below 2600 K, the lowest available temperature in the model grid.

Figures 4-5 combine the results of analysing the light curves and fitting the SEDs for all 36 stars considered here. For illustrative purposes, the observations are compared to the predictions of a synthetic AGB evolution code. The code was written by Dr. J. Wagenhuber in 1998 just before he left astronomy, and basically implements the recipes described in Wagenhuber & Groenewegen (1998). The output of the code is the time evolution of various stellar quantities. The luminosity and effective temperature are first combined to calculate the stellar radius, and then with the current stellar mass to estimate the fundamental pulsation period, taking the pulsation constant from Wood (1990). The model shown in Fig. 4 is for a 4 $M_{\odot}$ star, and the output of the model is sampled every 10^3 years. It is assumed that pulsation (in the fundamental mode) takes place the entire AGB phase.

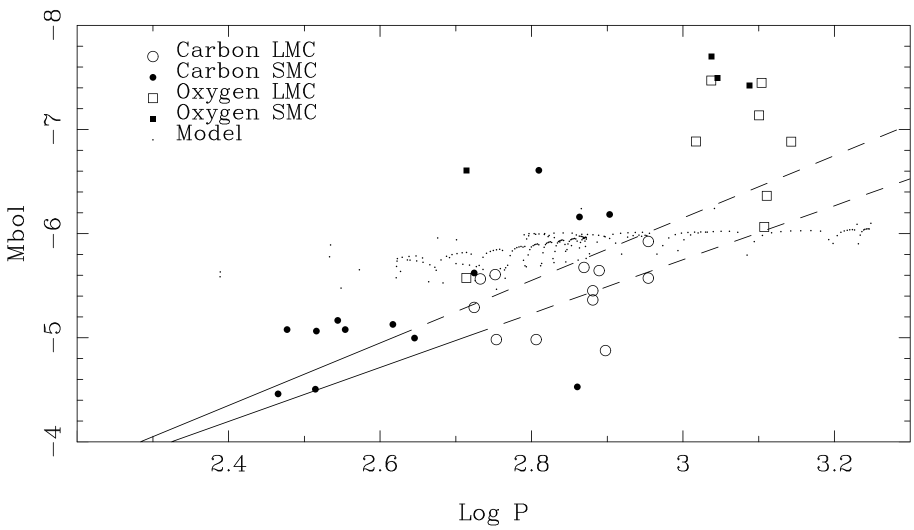

Figure 4. The PL-diagram from the stars studied here. Galaxy and chemical type are indicated by different symbols. The two straight lines represent the PL-relation for oxygen-rich and carbon-rich Miras in the LMC (respectively the upper line from Feast et al. 1989, and the lower line from Groenewegen & Whitelock 1996), the solid part indicating the period range over which these relations were derived, and the dashed part indicating the extension. The dots represent the evolution of a 4 $M_\odot$ star from its first thermal pulse to the Post-AGB phase, pulsating in the fundamental mode. Each dot corresponds to 10^3 years. Details of the evolution will depend on the assumed mass loss rate law.

Figure 4 shows the period-luminosity diagram, including previously derived relations (see caption). The scatter is considerable. The determination of the luminosities are not corrected for the phase of the light curve – and doing so would lead to less scatter – but it seems very unlikely that the true dispersion is as small as the about 0.15 mag that is typically found in PL-relations derived for $P \lesssim 400$ days (Feast et al. 1989, Groenewegen & Whitelock 1996).

Figure 5 shows the relation between mass loss rate and pulsation period. The carbon stars seem to follow quite closely the relation derived in Groenewegen et al. (1998) for Galactic Carbon Miras. In order words: no evidence is seen for a clear explicit dependence of mass loss rate on metallicity. However, a detailed comparison is not straightforward as it involves poorly known quantities as the dust-to-gas ratio and dust opacities in the two galaxies.

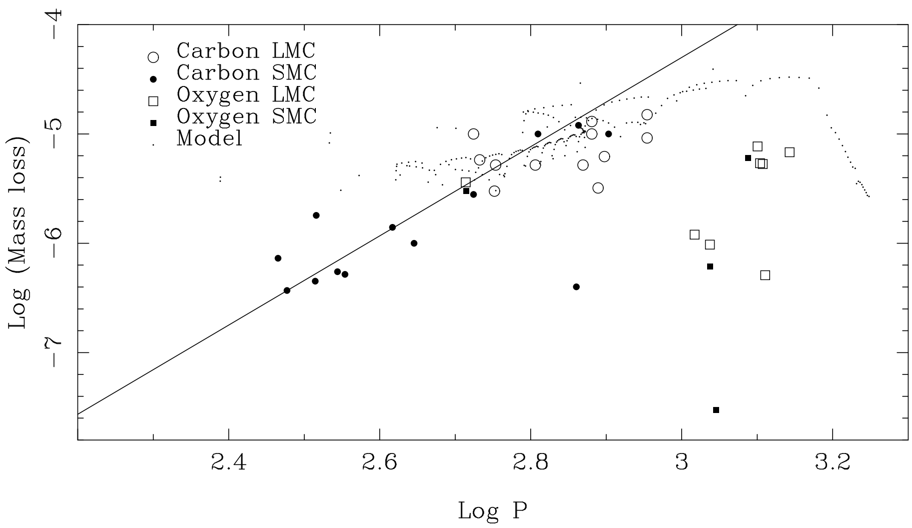

Figure 5. The relation between period and mass loss rate. Symbols as in the previous figure. The line represents the relation derived in Groenewegen et al. (1998) for Galactic carbon-rich Miras.

Acknowledgments

I would like to thank Adam Frankowski (Torun, Poland) for "reviving" the numerical code from Josef Wagenhuber's scientific legacy, during a 3-week visit to the astronomical institute in Leuven in April 2002, and Cecile Loup (IAP, Paris) for providing the list of objects in the SMC "minisurvey".

This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by NASA and the NSF.

This paper utilizes public domain data obtained by the MACHO Project, jointly funded by the US Department of Energy through the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48, by the National Science Foundation through the Center for Particle Astrophysics of the University of California under cooperative agreement AST-8809616, and by the Mount Stromlo and Siding Spring Observatory, part of the Australian National University.

References

Cioni M.-R., Loup C., Habing H.J., et al., 2000, A&AS 144, 235

Cioni M.-R., Marquette J.-B., Loup C., et al., 2001, A&A 377, 495

Feast M.W., Glass I.S., Whitelock P.A., Catchpole R.M., 1989, MNRAS 241, 375

Fluks M.A., Plez B., Thé P.S., et al., 1994, A&AS 105, 311

Groenewegen M.A.T., 1993, Ph.D. Thesis, Chapter 5, University of Amsterdam

Groenewegen M.A.T., Whitelock P.A., 1996, MNRAS 281, 1347

Groenewegen M.A.T., Blommaert J.A.D.L., 1998, A&A 332, 25

Groenewegen M.A.T., Whitelock P.A., Smith C.H., Kerschbaum F., 1998, MNRAS 293, 18

Groenewegen M.A.T., van Loon J.Th., Whitelock P.A., Wood P.R., Zijlstra A.A., 2000, in: "IAU Symposium 177: The Carbon Star Phenomenon", Ed. R.F. Wing, Kluwer Publishing, p. 385

Hughes S.M.G., 1989, AJ 97, 1634

Loidl R., Lançon A., Jorgensen, U. G., 2001, A&A 371, 1065

Loup C., Zijlstra A.A., Waters L.B.F.M., Groenewegen M.A.T., 1997, A&AS 125, 419

Payne-Gaposchkin C.H., 1971, Smithsonian Contrib. Astrophys. 13,1

Reid N., Tinney C., Mould J, 1990, ApJ 348, 98

Reid N., 1991, ApJ 382, 143

Reid I.N., Hughes S.M.G., Glass I.S., 1995, MNRAS 275, 331

Sperl M., 1996, DSSN 10, 5

Trams N.R., van Loon J.Th., Waters L.B.F.M., et al., 1999, A&A 346, 843

van Loon J.Th., Zijlstra A.A., Whitelock P.A., et al., 1997, A&A 325, 600

van Loon J.Th., Zijlstra A.A., Whitelock P.A., et al., 1998, A&A 329, 169

van Loon J.Th., Groenewegen M.A.T., de Koter A., et al., 2000, A&A 351, 559

Wagenhuber J., Groenewegen M.A.T., 1998, A&A 340, 183

Whitelock P.A., Feast M.W., Menzies J.W., Catchpole R.M., 1989, MNRAS 238, 769

Wood P.R., 1990, in: "From Miras to Planetary nebulae", p. 67

Wood P.R., Whiteoak J.B., Hughes S.M.G., et al., 1992, ApJ 397, 552

Wood P.R., 1998, A&A 338, 592

Wood P.R., Alcock C., Allsman R.A., et al., 1999, in: "IAU Symposium 191: Asymptotic Giant Branch Stars", Eds. T. Le Bertre, A. Lebre, and C. Waelkens, p. 151

Wood P.R., 2000, PASA 17, 18

Zijlstra A.A., Loup C., Waters L.B.F.M., et al., 1996, MNRAS 279, 32