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Pulsation of AGB stars in the Small Magellanic Cloud cluster NGC 419

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Abstract. The Magellanic Clouds are excellent laboratories to study and test theories of the late stages of stellar evolution. Our understanding of the evolution of red giants, and mass loss from them, is limited owing to uncertainties in determining important stellar parameters such as the initial mass and metallicity. A powerful way to overcome this is to study red giants in clusters for which the age, and hence the initial mass of the red giants, can be obtained with accuracy. The initial metallicity can also be obtained by studying stars less extreme than the AGB stars. Here, we present preliminary results of a study of AGB stars in the cluster NGC 419 belonging to the Small Magellanic Cloud (SMC). Using the pulsation behaviour of AGB variables in this cluster, we derive their current masses and find that significant amounts of mass loss have occurred at the tip of the AGB.

Key words. Stars: AGB and post-AGB – Stars: mass-loss – Stars: variables: general – Galaxies: Magellanic Clouds – Globular clusters: NGC 419

1. Introduction

The intermediate age SMC cluster NGC 419 is the only cluster in the SMC which is known to have AGB stars with extremely high mass-loss rates. The cluster contains one very red star detected first in the mid-IR (Tanabé et al. 1998) and one star first seen in the near-IR (Tanabé et al. 1997). Both these stars have dense, dusty circumstellar shells resulting from high mass-loss rates. The cluster also contains many carbon-rich AGB stars.

Recent HST observations show that NGC 419 has a broad main-sequence turnoff which is interpreted as the result of multiple star formation events or extended star formation (Glatt et al. 2008; Girardi et al. 2009; Rubele et al. 2010). The metallicity of NGC 419 is close to [Fe/H] = -0.7 (Kayser et al. 2009), corresponding to a metallicity of Z ≈ 0.004. Fits to the Hertzsprung-Russell diagrams yield ages of 1.2-1.8 Gyr (Glatt et al. 2008; Girardi et al. 2009; Rubele et al. 2010). We adopt an age of 1.4±0.2 Gyr. For this age, the isochrones of Girardi et al. (2000) with a metallicity of Z=0.004 yield an initial mass for stars currently at the beginning of the thermally pulsing asymptotic giant branch (TPAGB) of 1.82±0.15 $M_\odot$. As a result of mass loss prior to the TPAGB, the actual current mass is estimated to be 1.79±0.15 $M_\odot$

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(according to the Girardi et al. (2000) evolutionary tracks which use a scaled Reimers' mass-loss law).

2. Observational data

The extreme mid-IR source and the near-IR source in NGC 419 were long ago assumed to be AGB stars with a large pulsation amplitude. Therefore, the cluster was monitored relatively sparsely in time over approximately 3000 days with the 2.3m telescope of the Australian National University at Siding Spring Observatory. The observations were taken using the near-IR Cryogenic Array Spectrometer/Imager (CASPIR) (McGregor et al. 1994). The observations were carried out using the filters J (1.28μm), H (1.68μm), K (2.22μm) and L (3.59μm). These observations were used to determine the periods of the mid-IR and near-IR sources. They also gave very good mean JHKL magnitudes for the other variable and non-variable AGB stars in the cluster.

Most of the other AGB stars have relatively low amplitude variability. Unfortunately, this variability is far from regular and the near-IR observations are not adequate for determining periods. In order to derive periods for these stars, closely spaced (near-daily) observations are required in a bluer part of the spectrum where the amplitude is relatively large. We used data from the Optical Gravitational Lensing Experiment (OGLE II, Zebruń et al. 2001) supplemented with some OGLE III data.

Finally, in order to obtain the complete spectra enery distribution, the Spitzer Space Telescope (SST) Survey of the SMC by Bolatto et al. (2007) was used to obtain photometric data in the bands at 3.6, 4.5, 5.8, 8 and 24 μm.

3. Light curves and pulsation periods

In the OGLE data, sixteen stars were found to have significant variability. All the stars had semi-regular light curves and most showed multi-periodicity. The light curves were analysed using the phase dispersion minimization (PDM) task in IRAF. The values obtained were cross checked using the Period04 software, an extended version of Period98 by Sperl (1998).

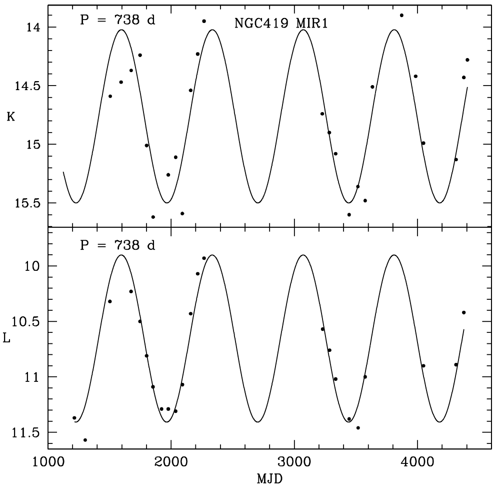

Fig. 1. K and L band light curves of the mid-IR variable in NGC 419.

For the mid-IR source, the near-IR photometric observations (K and L bands) provided good light curves: the mid-IR source was not detected by the OGLE survey. Fig. 1 shows the K and L light curves of the mid-IR source, along with Fourier fits to them.

4. Linear pulsation models

The first step in the modelling process was the construction of a fiducial giant branch for the non-variable AGB stars in the ($M_{\rm bol}$, $\log T_{\rm e}$ff) plane. The averaged J and K magnitudes from the CASPIR observations were used to do this. An SMC distance modulus of 18.93 and a foreground reddening E(B-V) of 0.12 was adopted (Keller & Wood 2006). For the O-rich stars in the cluster $K_{\rm o}$ and $(J\text{-}K)_{\rm o}$ were converted to $\log(L/L_{\odot})$ and $T_{\rm eff}$, using the transforms in Houdashelt et al. (2000a,b). For the C-rich stars, the bolometric correction in Wood et al. (1983) was used while the ($(J\text{-}K)_{\rm o}$,$T_{\rm eff}$) relation from Bessell et al. (1983) gave $T_{\rm eff}$.

For the variable stars, the luminosity was obtained by integration under the spectral energy distribution, corrected for foreground extinction. For the large amplitude near-IR and mid-IR sources, the mid-IR spectral energy

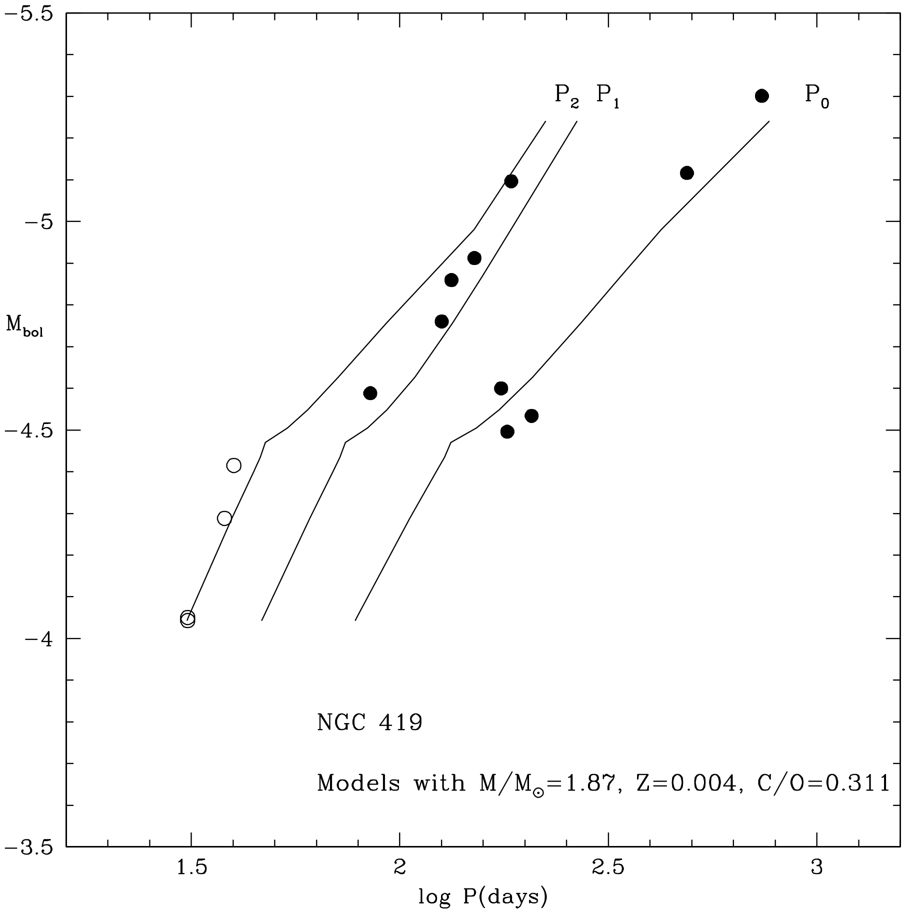

Fig. 2. The $M_{\rm bol}$ vs $\log P$ diagram for the AGB variables in NGC 419. The open symbols denote the M stars and the closed symbols denote the C stars.

distributions from the Spitzer observations of Groenewegen et al. (2007) were used. In order to correct for the fact that the mid-IR Spitzer observations were taken at only one pulsation phase, it was assumed that $M_{\rm bol}$ and the L magnitude have the same amplitude of variation. Then the computed values of $M_{\rm bol}$ at the time of Spitzer observation was corrected to the mean value using the difference between L at time of the Spitzer observation and the mean L.

For the small amplitude variables in NGC 419, we constructed static and linear non-adiabatic pulsation models which are based on the pulsation codes described in Fox & Wood (1982) and updated by Keller & Wood (2006). At temperatures below $\log T = 3.75$, we used Rosseland mean opacities computed using AESOPUS (Marigo & Aringer 2009). Some of the mixtures used had C/O > 1. The core mass, $M_{\rm c}$, was obtained from the $L - M_{\rm c}$ relation of Wood & Zarro (1983).

To derive the mixing length and the stellar mass early in the TPAGB, we considered the least luminous variable, where C/O was assumed to be 0.31. Given the fiducial giant branch temperature at the $M_{\rm bol}$ of this variable, along with the period of the variable, the mixing length and the stellar mass were adjusted until the model had the correct $T_{\rm eff}$ and the correct P. The mixing length and the mass were then kept constant for all other linear models at different luminosities. We found that a mass of 1.87 $M_\odot$ fit the observed periods best. Fig. 2 shows the preliminary ($M_{\rm bol}$, $\log P$) diagram for the AGB variables in NGC 419. The reasonable fit of the models to the observed periods suggests than mass loss is relatively small for the small amplitude variables with $\log P < 2.5$ days. A similar small amount of mass loss was found in the pulsation studies of AGB stars in the Large Magellanic Cloud cluster NGC 1846 (Lebzelter & Wood 2007).

5. Nonlinear pulsation models

The above linear models are inappropriate for the large amplitude mid-IR and near-IR stars in the cluster (these are the two stars with $\log P >$ 2.5 days in Fig. 2). At large amplitude, long period variables can have very different linear and nonlinear periods (e.g. Lebzelter & Wood 2005).

Fig. 3 shows a non-linear pulsation calculation for the mid-IR source in NGC 419. In order to reproduce the observed period, it was found that a mass of 1.6 $M_\odot$ was required. This mass, compared to the mass of the small amplitude AGB stars, shows that 0.27 $M_\odot$ have been recently lost in a superwind from this star. The mass must have been lost near $M_{\rm bol} = -5.3$. The star still has about 1 $M_\odot$ to lose, which will take about 6×10^4 years if we use the mass-loss rate of 1.7×10^{-5} $M_\odot$/yr given by Groenewegen et al. (2007) for this star.

6. Future work

We intend to continue this work and construct a nonlinear pulsation model for the near-IR source in NGC 419. Similar work will also be carried out for the LMC cluster NGC 1978. The accurate masses obtained from the pulsation models will be used to derive the mass-loss rates at different L and M values. The results will be used to constrain mass-loss rate formulae for AGB stars since all the parameters (M, L, P) normally used in these formulae are known for these stars.

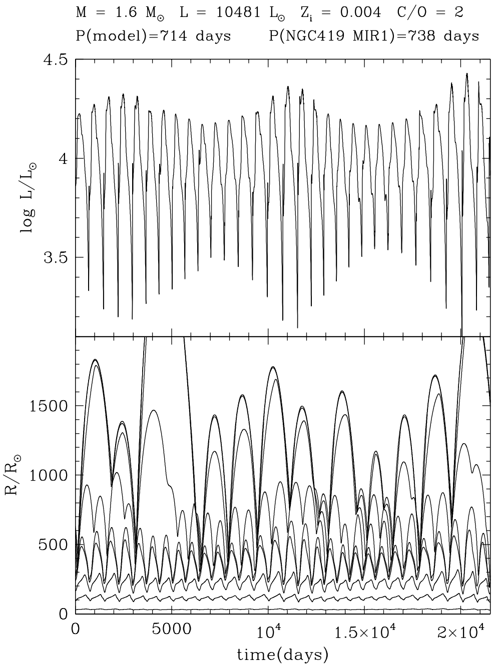

Fig. 3. A non-linear pulsation model for the mid-IR source in NGC 419. The top panel shows the surface luminosity as a function of time while the bottom panel shows the time variation of the radial position of various mass elements in the stellar envelope.

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References

Bessell, M. S., Wood, P. R., & Evans, T. L. 1983, MNRAS, 202, 59
Bolatto, A. D., Simon, J. D., Stanimirović S., et al. 2007, ApJ, 655, 212
Fox, M. W., & Wood, P. R. 1982, ApJ, 259, 198
Girardi, L., Bressan, A., Bertelli, G., & Chiosi, C. 2000, A&AS, 141, 371
Girardi, L., Rubele, S., & Kerber, L. 2009, MNRAS, 394, L74
Glatt, K., Grebel, E. K., Sabbi, E., et al. 2008, AJ, 136, 1703
Groenewegen, M. A. T., Wood, P. R., Sloan, G. C., et al. 2007, MNRAS, 376, 313

Houdashelt, M. L., Bell, R. A., Sweigart, A. V., & Wing, R. F. 2000a, AJ, 119, 1424
Houdashelt, M. L., Bell, R. A., & Sweigart, A. V. 2000b, AJ, 119, 1448
Kayser, A., Grebel, E. K., Harbeck, D. R., et al. 2009, Globular Clusters - Guides to Galaxies, Springer (Berlin/Heidelberg), 157
Keller, S. C., & Wood, P. R. 2006, ApJ, 642, 834
Lebzelter, T., & Wood, P. R. 2005, A&A, 441, 1117
Lebzelter, T., & Wood, P. R. 2007, A&A, 475, 643
Marigo, P., & Aringer, B. 2009, A&A, 508, 1539
McGregor, P., Hart, J., Hoadley, D.,& Bloxham, G., 1994, in Infrared Astronomy with Arrays, ed. I. McLean (Kluwer), 299
Rubele, S., Kerber, L., & Girardi, L. 2010, MNRAS, 403, 1156
Sperl, M. 1998, Communications in Asteroseismology, 111, 1
Tanabé, T., & Nishida, S. 1997, Astronomical Herald, 90, 214
Tanabé, T., Nishida, S., Nakada, Y., et al. 1998, Ap&SS, 245, 407
Wood, P. R., & Zarro, D. M. 1981, ApJ, 247, 247
Wood, P. R., Bessell, M. S., & Fox, M. W. 1983, ApJ, 272, 99
Zebruń, K., Soszyński, I., Wozniak, P. R., et al. 2001, Acta Astronomica, 51, 317