Asymptotic Giant Branch Stars
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Systematic study of AGB stars in the intermediate-age globular clusters in the Magellanic Clouds[1]

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Abstract.

We performed systematic infrared observations of the intermediate-age Magellanic Clouds clusters NGC 419, NGC 1783 and NGC 1978. Mid-infrared stars discovered in NGC 419 and NGC 1978 are very red and must be undergoing intense mass loss (comparable to superwinds). They are probably carbon stars but do not seem to show any FIR excesses. Three optically visible carbon stars as well as (at least) 2 near-infrared carbon stars observed with ISOPHOT show 60 μm excesses which may indicate mass loss in the past. It seems that the MIR stars are fainter than the AGB tip luminosity and that their $M_{\rm bol}$s are close to those of the transition luminosity from M type to C stars. Therefore, these MIR stars may not be in the final stage of the AGB phase. This may suggest that AGB stars lose mass heavily at some other time, possibly during the transition from M type to C stars.

1. Introduction

Globular clusters (GCs) are thought to be an ideal test field for the theory of stellar evolution. However, GCs in our Galaxy are all old and their number is

[1]Based on observations with ISO, an ESA project with instruments funded by ESA Member states (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with participation of ISAS and NASA.

limited. In contrast, GCs associated with the Magellanic Clouds (MCs) span a wide range of age, which enables us to study the evolution of stars with various masses. Furthermore, GCs are numerous in the MCs and this richness makes them particularly suitable for studying the short-lived late stages of stellar evolution.

Toward the end of the AGB phase, AGB stars are thought to undergo heavy mass loss and to be surrounded by thick circumstellar dust shells. It is, therefore, expected that AGB stars become very red, perhaps not even visible in the near-infrared (NIR). Thus, observations in the mid-infrared (MIR) are likely to be important for the study of the late stages of stellar evolution.

We have performed systematic observations of AGB stars in GCs in the MCs with ISO (Kessler et al. 1996) in the MIR and with a ground-based telescope in the NIR. We here report the results of NIR and MIR observations of intermediate-age clusters, NGC 419, NGC 1783 and NGC 1978, and discuss the evolution of low- to intermediate-mass stars. The ages of the clusters are estimated to be 1–2 Gyr which roughly corresponds to a turn-off-mass of 1.5 to 2 $M_{\odot}$.

2. Observations

The ISO observations consist of CAM broad band (LW1, LW2, LW10) images and CAM CVF spectra. For 7 infrared bright AGB stars belonging to 3 clusters, we also performed PHOT 25 and 60 μm photometry. CAM data were reduced with the *ISOCAM Interactive Analysis (CIA)* [2] version 2.0 and the photometry was done with *IRAF/DAOPHOT*. PHOT data were reduced with *ISOPHOT Interactive Analysis (PIA)* [3] version 7.1.

NIR observations have been carried out at the South African Astronomical Observatory since 1993. The main results come from J, H and K broad band imaging with the PtSi Astronomical Near-Infrared Camera, (PANIC) (Glass et al. 1994; Glass et al. 1995; Tanabé et al. 1996), attached to the Cassegrain focus of the 0.75 m telescope. We also observed several red AGB stars with the IR photometer at 1.9 m telescope.

3. Results and discussion

In the course of our NIR observations, we found 3 infrared stars (hereafter NIR stars) in these 3 clusters (Tanabé et al. 1997). One of the stars found in NGC 1978 was first discovered by Frogel et al. (1990). Repeated observations show that they are long period variables with $P \sim 400$–500 days (Nishida et al.). Furthermore, NIR spectroscopic observations show they are all carbon stars.

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[2]The ISOCAM data presented in this paper was analyzed using "CIA", a joint development by the ESA Astrophysics Division and the ISOCAM Consortium led by the ISOCAM PI, C. Cesarsky, Direction des Sciences de la Matière, C.E.A., France.

[3]PIA is a joint development by the ESA Astrophysics Division and the ISOPHOT Consortium led by the Max Planck Institute for Astronomy (MPIA), Heidelberg. Contributing ISOPHOT Consortium institutes are DIAS, RAL, AIP, MPIK, and MPIA.

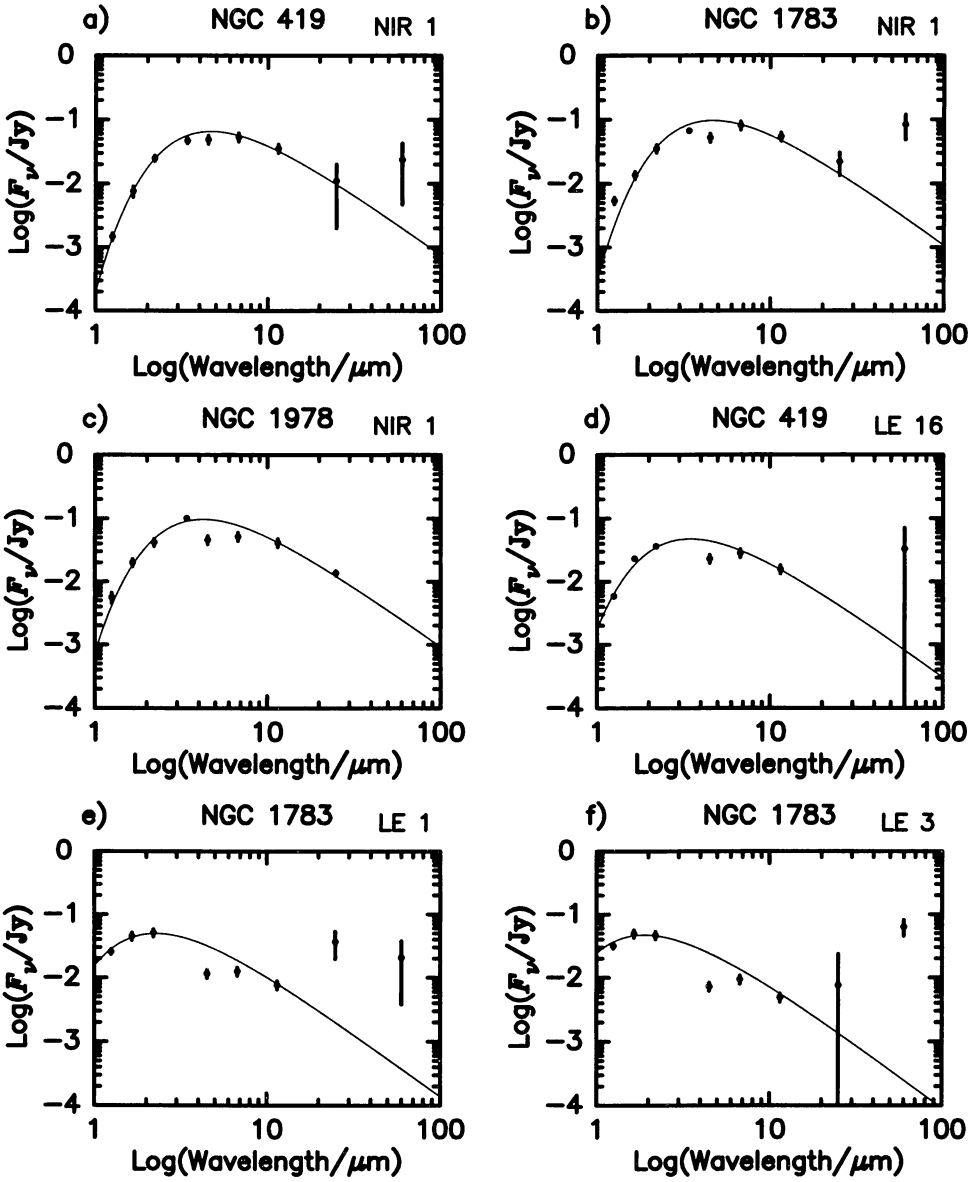

Figure 1. Spectral energy distributions of a) NGC 419 NIR 1, b) NGC 1783 NIR 1, c) NGC 1978 NIR 1, d) NGC 419 LE 16, e) NGC 1783 LE 1, and f) NGC 1783 LE 3. J, H, and K data of NIR stars are the mean values of the lightcurves. Those of the other stars are from Frogel et al. (1990). Each solid curve is a blackbody fit to the photometric data.

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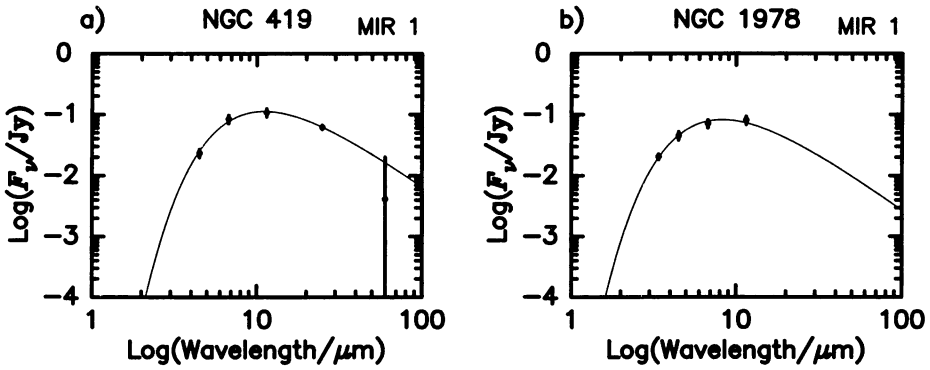

Figure 2. Spectral energy distribution of a) NGC 419 MIR 1 and b) NGC 1978 MIR 1. Each solid curve is a blackbody fit to the photometric data.

ISO PHOT observations of NGC 419 NIR 1 and NGC 1783 NIR 1 revealed 60 μm excesses. We observed 3 other optically identified infrared-bright carbon stars with PHOT and they also show 60 μm excesses. Fig. 1 shows the spectral energy distributions of these stars. We think that this far-infrared excess is indicative of mass loss in the past. This may be evidence that stars in the AGB phase repeat the thermal pulses which are associated with increased mass loss.

ISOCAM observations revealed much redder stars (hereafter MIR stars) in NGC 419 and NGC 1978 (Tanabé et al. 1998). NGC 1978 MIR 1 can be seen in the deep K-band image but NGC 419 MIR 1 has not yet been identified. Fig. 2 shows their spectral energy distributions. From their extreme redness, these stars must be experiencing intense mass loss, possibly caused by superwinds. CAM CVF spectra of these stars show broad emission features around 11.5 μm which are similar to the one observed in carbon stars. CVF spectra also show broad absorptions around 7–8 μm which are probably due to HCN and/or C_2H_2 molecules. Thus, these stars are thought to be carbon stars. However, contrary to the optically-visible and NIR carbon stars mentioned above, NGC 419 MIR 1 does not show any far-infrared excess.

We plot color-magnitude diagrams of AGB stars in these 3 clusters in Fig. 3. Bolometric magnitudes, $M_{\rm bol}$, of NIR and MIR stars in the 3 clusters were estimated by simply fitting blackbody curves to the flux data. We have not included the contributions of far-infrared excesses, if any, in the bolometric magnitudes. $M_{\rm bol}$ of optically-visible stars are taken from Frogel et al. (1990). Here, we have adopted $m - M = 18.5$ for the LMC and 18.9 for the SMC. We can clearly see the sequence from oxygen-rich through carbon stars to NIR stars and these stars constitute direct evidence that AGB stars go through a superwind phase (Renzini 1981). However, it seems that the MIR stars are fainter than the AGB tip luminosity and that their $M_{\rm bol}$s are close to those of the transition luminosity from M type to C stars. It has been established that the luminosity of a star increases toward the end of the AGB phase (see the core-mass luminosity relation of Paczyński 1970). Therefore, these MIR stars may not be in the final

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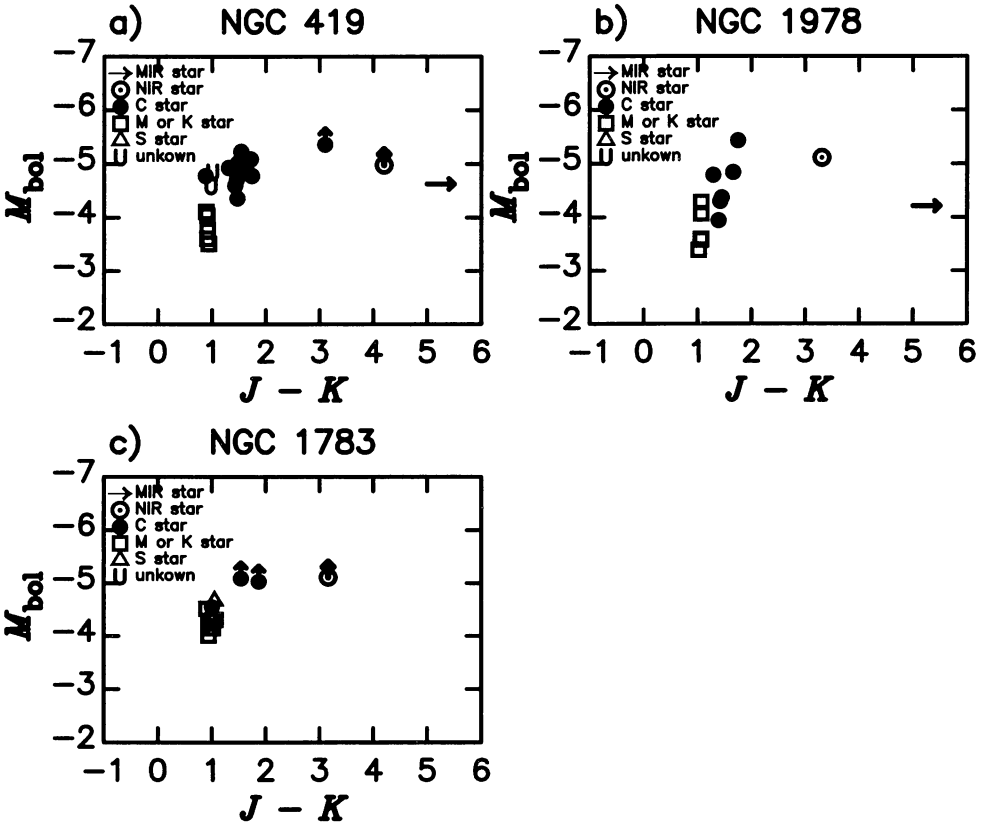

Figure 3. Color magnitude diagram of AGB stars in a) NGC 419, b) NGC 1978, and c) NGC 1783

stage of the AGB phase. This may suggest that AGB stars lose mass heavily at some other time, possibly during the transition from M type to C stars.

However, the conclusion above should await further observations, especially in the NIR. ISOCAM observations together with NIR photometry indicate that many AGB stars, both M type and C stars, have a rather deep absorption around 4.5 μm (see Fig. 1) possibly due to CO molecules and around 7–8 μm, the absorption already mentioned above. Thus, simple blackbody fitting may lead to a lower apparent luminosity. Also, it is possible that these MIR stars are variable and that we observed them at the minimum phase.

4. Summary

1. MIR stars discovered in the intermediate-age clusters NGC 419 and NGC 1978 are very red and must be undergoing intense mass loss (comparable to

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superwinds). They are probably carbon stars but do not seem to show any FIR excesses.

2. Three optically visible carbon stars as well as (at least) 2 NIR carbon stars observed with ISO PHOT show 60 μm excesses which may indicate mass loss in the past. Their absolute luminosities are higher than those of MIR stars.

3. The bolometric magnitudes of MIR stars seem to be close to that of the transition luminosity from M type to C stars. This suggests that they are not in the final stage of the AGB.

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