Part 5

Red Giants, Miras, post-AGB stars and proto-planetary nebulae

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press

Variable Stars in the Local Group
ASP Conference Series, Vol. 310, 2004
Donald W. Kurtz & Karen R. Pollard, eds.

Properties of AGB variables in the intermediate-age cluster NGC 419 in the SMC

Toshihiko Tanabé[1], Yoshifusa Ita[1], Noriyuki Matsunaga[1], Yoshikazu Nakada[1,2], IRSF/SIRIUS team[3,4]

[1]*Institute of Astronomy, School of Science, The University of Tokyo, Mitaka, Tokyo, 181-0015, Japan*
[2]*Kiso Observatory, School of Science, The University of Tokyo, Mitake, Kiso, Nagano, 397-0101, Japan*
[3]*Department of Astrophysics, Nagoya University, Chikusa-ku, Nagoya, 464-8602, Japan*
[4]*National Astronomical Observatory of Japan, Mitaka, Tokyo, 181-0015, Japan*

Abstract. We found that the OGLE database contains most AGB stars associated with the SMC cluster NGC 419. Combining these data with our near-infrared (NIR) data, we obtained the following results: 1) Almost all AGB stars above the TRGB are variables. 2) Large amplitude variables tend to show more regular light curves. 3) Only the tip AGB stars (in this case, carbon stars) increase their amplitudes with their $J-K$ colors and only the most evolved ones can become large amplitude (Mira-like) variables. 4) AGB variables may explain the sequences found by Wood et al. (1999).

1. Introduction

About five years ago, Wood et al. (1999) discovered several sequences in the Period-Luminosity diagram for long period variables in the Large Magellanic Cloud (LMC). Later observations (Cioni et al. 2001; Noda et al. 2002; Ita et al., these proceedings) confirmed and refined them. Because of the high luminosity, sequences A, B, and C are considered to be related to AGB stars. Furthermore, the formerly defined Mira sequence of Feast et al. (1989) and Hughes & Wood (1990) clearly corresponds to sequence C (Wood 2000). However, the variability of stars on the AGB has not been studied systematically. In order to clarify these sequences and the properties of AGB variables, we think a systematic search for AGB variables with known physical parameters is important and we started NIR monitoring observations of globular clusters (GCs) in the Magellanic Clouds. GCs are always important objects for studying stellar evolution. And, GCs especially in the Magellanic Clouds have an advantage over those in our Galaxy. They span a wide range in ages, which enables us to study the evolution of stars with various masses.

Here, we discuss AGB variables associated with NGC 419 in the Small Magellanic Cloud (SMC). NGC 419 is an intermediate-age cluster (SWB V: Searle,

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press

Wilkinson & Bagnuolo 1980; age ~1.2 Gyr: Duran, Hardy & Melnick 1984). It is one of the most populous clusters in the Magellanic Clouds and contains more than 30 AGB stars (Frogel, Mould & Blanco 1990). Furthermore, we found that the OGLE (Optical Gravitational Lensing Experiment) database contains most of these AGB stars in NGC 419. We combined these data with our NIR data and will try to deduce the properties of AGB variables.

2. NIR Observations

NIR observations are being carried out with the newly built 1.4-m telescope, IRSF (InfraRed Survey Facility), at the Sutherland station of the South African Astronomical Observatory. The telescope is equipped with a 3-channel NIR camera, SIRIUS (Simultaneous 3 color InfraRed Imager for Unbiased Survey; Nagayama et al. 2001) that allows J, H, K_s images to be obtained simultaneously. The field of view is 7.8′ square with a scale of 0.45″/pixel. We so far observed NGC 419 ~20 times over the last 2 yr and found that AGB stars near the tip luminosity are variables.

The images obtained were processed by means of the standard SIRIUS pipeline which is based on the IRAF software, and photometry is carried out with the aid of DoPHOT (Schechter, Mateo & Saha 1993). The magnitudes are referred to the Las Campanas Observatory (LCO) system ones based on observations of a few dozen stars from Persson et al. (1998). The interstellar extinction toward the SMC is thought to be small and we neglect it.

3. OGLE data

We found that the OGLE survey includes the area toward NGC 419 and that the database contains 24 variables within 1.5′ of the center of NGC 419 (α = 01:08:18.00, $\delta = -72$:53:05.0). Among them, 21 stars are turned out to be formerly-known or probable AGB stars. We applied the Phase Dispersion Minimization (PDM) technique (Stellingwerf 1978) to determine the periods of these variables. We searched the minimum of the statistic parameter, θ, throughout the trial periods. If a star shows multi-periodicity, we carefully inspected the folded light curves by eye and multiple components are included, if real. In Table 1 we list these OGLE variables along with J, H, K magnitudes, the amplitudes of light variation at J and I, and θ. We define "amplitude" to be the peak-to-peak difference of the magnitudes between the brightest and the faintest. θ is a measure of regularity or periodicity. Star names follow those of NIR1 by Tanabé et al. (1997), for LE numbers by Lloyd Evans (1980a), and for 4-133, 5-3, 5-15 by Arp (1958).

We found that the less luminous OGLE 010825.44-725153.7 and 010814.87-725345.6 are Cepheids and 010809.65-725210.6 is probably a Cepheid-like variable; we will not discuss them here.

Table 1. NIR photometry and period of individual OGLE source in NGC 419

name	OGLE name	J	H	K	ΔJ	ΔI	P (d)	θ
NIR1	010812.92-725243.7	14.46	12.63	11.18	1.29	2.26	480.4	0.220
LE16	010801.10-725317.1	13.50	12.08	11.09	0.67	1.26	416.8	0.183
							213.6	0.392
LE18	010824.89-725256.7	12.77	11.61	10.95	0.21	0.44	441.7	0.252
							188.4	0.776
							149.2	0.823
LE19	010823.43-725318.2	13.34	12.48	12.28	0.08	0.07	123.3	0.627
							30.7	0.635
LE20	010811.55-725314.7	12.69	11.60	11.03	0.43	0.54	514.5	0.424
							323.3	0.506
							157.6	0.660
LE21	010812.36-725315.5	12.77	11.65	11.03	0.16	0.51	322.1	0.352
							233.5	0.718
LE22	010822.23-725302.3	12.90	11.81	11.21	0.41	0.57	500.1	0.371
							247.4	0.519
							130.5	0.810
LE23	010821.67-725302.7	12.78	11.77	11.28	0.36	0.56	428.0	0.300
							215.9	0.548
							147.2	0.657
LE24	010815.73-725254.3	13.03	12.18	11.98	0.07	0.09	143.7	0.763
							72.2	0.816
LE25	010815.63-725251.6	12.55	11.56	11.11	0.27	0.34	586.4	0.218
							441.2	0.485
							221.1	0.501
LE27	010820.61-725251.7	12.69	11.58	10.97	0.32	0.82	574.4	0.441
							324.9	0.576
							227.1	0.768
LE28	010821.50-725216.0	13.25	12.12	11.58	0.33	0.27	491.5	0.338
							237.2	0.513
							118.7	0.622
LE29	010822.28-725233.5	12.90	11.87	11.33	0.22	0.23	501.5	0.256
							276.7	0.698
							141.4	0.769
LE31	010820.37-725328.1	13.57	12.80	12.59	0.07	0.06	546.8	0.687
							76.9	0.766
LE32	010820.62-725222.0	14.20	13.43	13.26	0.06	0.03	544.8	0.773
LE35	010817.45-725301.1	12.46	11.35	10.77	0.30	0.57	340.6	0.478
							201.3	0.541
							166.4	0.579
4-133	010836.84-725339.6	12.92	12.05	11.73	0.19	0.30	437.5	0.449
							219.7	0.544
5-3	010814.58-725356.7	12.97	12.12	11.89	0.08	0.08	191.0	0.665
5-15	010823.80-725309.4	13.34	12.48	12.29	0.09	0.06	514.4	0.726
010810	010810.31-725307.6	13.89	13.00	12.60	0.24	0.40	466.8	0.439
							251.4	0.447
010817	010817.06-725305.3	13.36	12.53	12.35	0.12	0.06	288.2	0.729
010825	010825.44-725153.7	15.00	14.56	14.48	0.20	0.40	1.424	0.087
010814	010814.87-725345.6	16.61	16.08	16.00	0.28	0.24	21.54	0.147
010809	010809.65-725210.6	15.28	14.66	14.53	0.10	0.15	1.00	0.283

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press

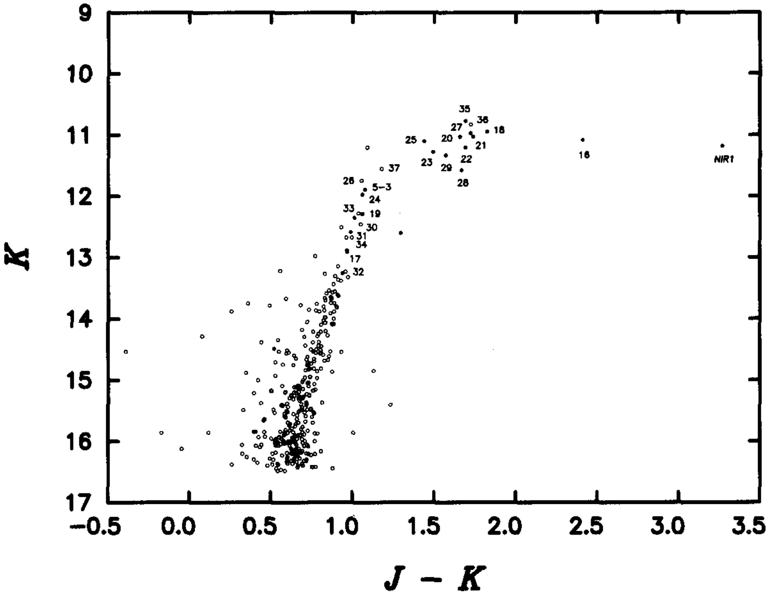

Figure 1. NIR color-magnitude diagram of stars within 1.5′ of the center of NGC 419. Stars with OGLE counterparts are shown with filled circles.

4. Results and discussion

4.1. AGB Stars in NGC 419

Fig. 1 is the NIR color-magnitude diagram of stars within 1.5′ of the center of NGC 419. This figure is drawn with the data taken on 2002 November 14 (one epoch data). The tip luminosity of the red giant branch (TRGB) is thought to be ~12.7 and all stars above this luminosity are regarded as AGB stars. We note that most stars with $J - K > 1.4$ are identified as carbon stars, while those with $J - K < 1.4$ are oxygen-rich (Lloyd Evans 1980a,b; Bessell, Wood & Lloyd Evans 1983). From this figure we can clearly see the evolutionary sequence of intermediate-mass stars. As a star evolves, it goes up along the AGB to the tip luminosity and then becomes a redder carbon star. The transition from oxygen-rich to carbon-rich may be very fast, since we see the gap between them. A star stays as a carbon star for a while and finally goes to a much redder obscured star because of the heavy mass-loss in a superwind phase.

4.2. Light Curves

It is clear that AGB stars in the OGLE database are variables. We plotted the light curves of all OGLE sources in Fig. 2. The reddest star, NIR1, show a large amplitude and relatively regular pulsation. Its light curve resembles that of a galactic carbon Mira. The second reddest star, LE16, shows a similar light curve. However, the light curves of other AGB stars are less regular. LE18,

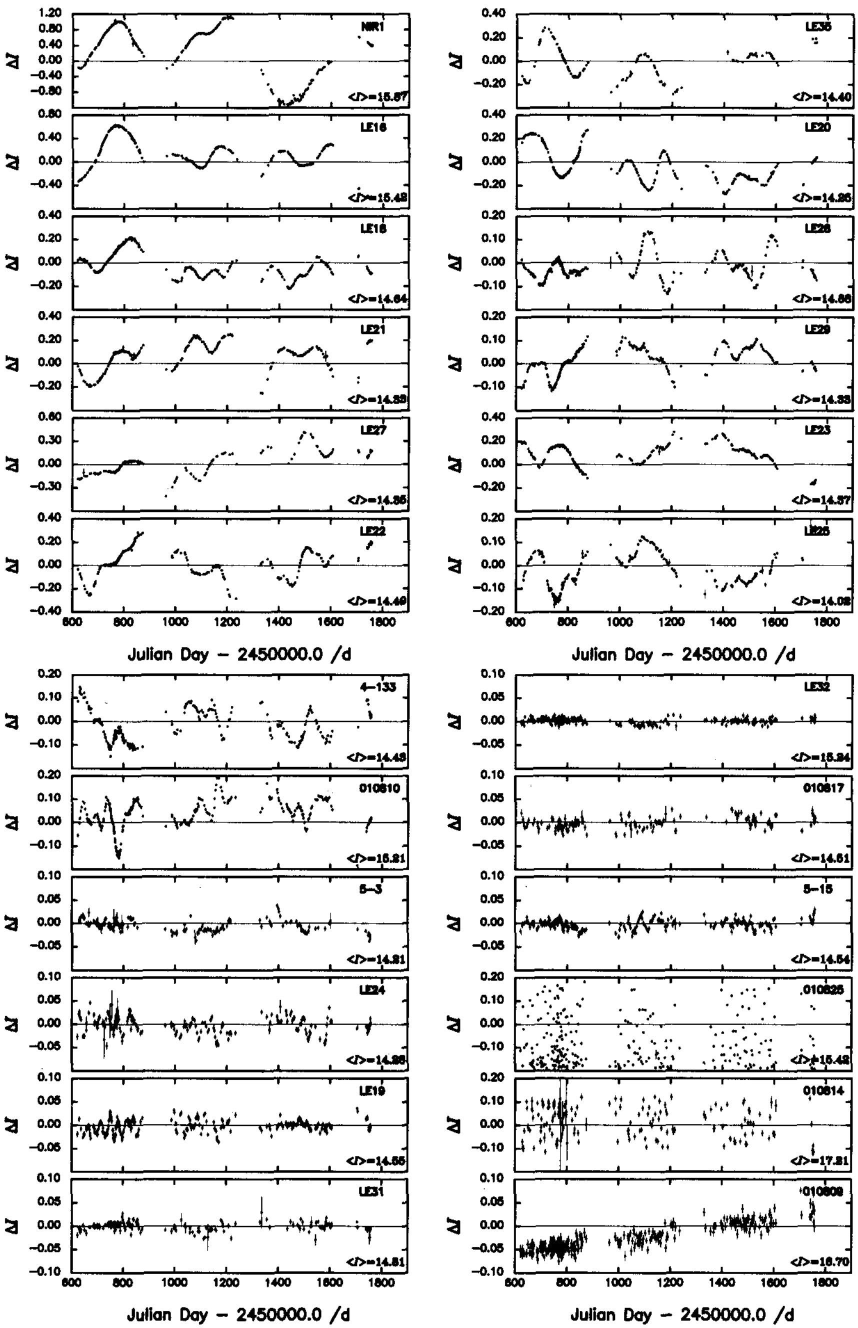

Figure 2. Light curve of OGLE variables in NGC 419. Note that the ordinate scales are different from star to star.

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press

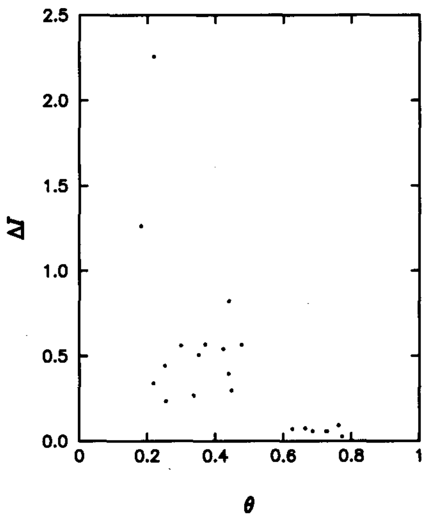

Figure 3. Amplitude vs θ. The θ value is the only minimum if the star is multi-periodic.

LE21 and LE28 show a multi-periodicity. LE20 and LE27 seem to show a long-term variation. The amplitudes of these stars are also small. The relationship between the amplitude and the regularity can be seen in Fig. 3. Large amplitude variables tend to show more regular light curves.

4.3. Properties of AGB variables

In Fig. 4, we plot the amplitude vs K and $J-K$ color. First, these figures clearly show that brighter and redder AGB stars show variability. Taking into account that the photometry is rather difficult in the dense central region, we may say that almost all AGB stars above TRGB are detected as variables by the OGLE survey (see also Fig. 1). We suggest that a star becomes an irregular and small-amplitude variable somewhere on the AGB when it is still oxygen-rich. Secondly, it seems that the amplitudes of AGB variables increase only after they reach the tip luminosity and they increase proportionally to their $J-K$ colors. In this population stars on the tip luminosity are carbon stars. Thus, only carbon stars as evolved as this increase their amplitudes, and can become large amplitude (Mira-like) variables only after they reach a final phase.

4.4. Period-K magnitude relation

In Fig. 5, we show the Period-K magnitude relation of these AGB variables. The left panel includes only the main period (θ minimum) while in the right panel multiple periods are included, if they exist. The solid lines labelled B+, C′, C and D are the sequences determined by Ita et al. (2004, these proceedings) taking into account the difference of the distance to the LMC and SMC being

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press

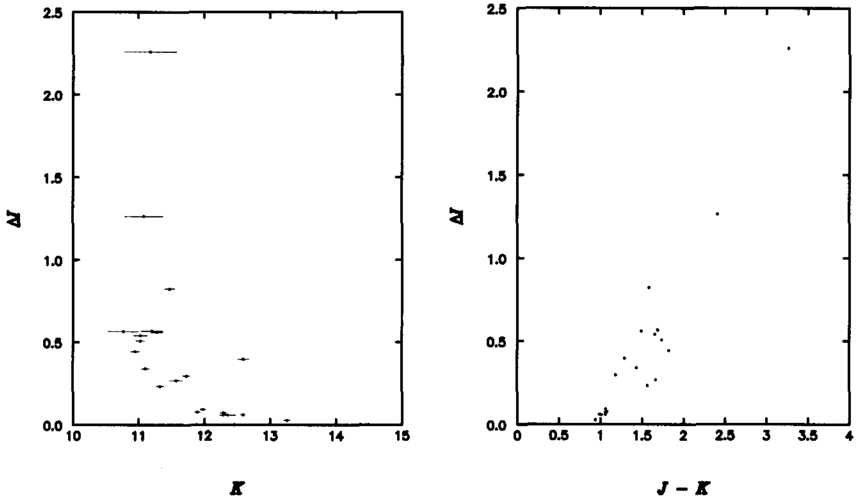

Figure 4. Amplitude vs K (left) and amplitude vs $J-K$ (right) diagram. The amplitude at K is shown as horizontal bar in the left panel.

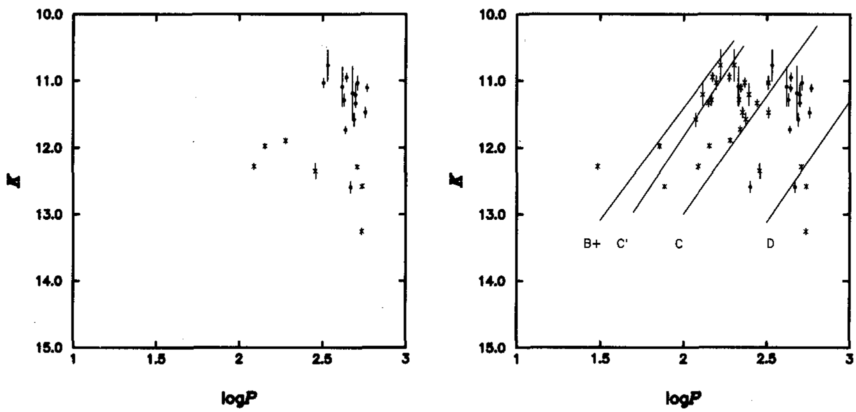

Figure 5. Period-K magnitude relation of AGB variables in NGC 419. Dots represent stars with good periodicity ($\theta < 0.5$) while crosses are less regular variables ($\theta > 0.5$). The amplitude at K is plotted as the individual error. The left panel includes only the main period (θ minimum) while the right panel shows multiple periods, if they exist. See text for C′, C, D.

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press

$\Delta(m - M) = 0.49$. The sequence C is essentially the same as that of the Miras determined by Feast et al. (1989) and Hughes & Wood (1990) in the LMC. The main body of AGB variables in NGC 419, which mainly consist of carbon stars, occupies a rather small region. As compared with the sequence C, it is located somewhat fainter and/or to the longer period side. We are currently not certain whether or not this is real. We rather think that it will be explained by other factors such as the depth of the SMC and the metallicity effect. However, the multimode components seem to form parallel sequence(s). If such a mode is enhanced by some reason during evolution, it can explain the sequence B^+ or C.

References

Arp, H.C. 1958, AJ, 63, 273

Bessell, M.S., Wood, P.R., Lloyd Evans, T. 1983, MNRAS, 202, 59

Cioni, M.-R.L., Marquette, J.-B., Loup, C., Azzopardi, M., Habing, H.J. Lasserre, T., Lesquoy, E. 2001, A&A, 377, 945

Duran, D., Hardy, E., Melnick, J. 1984, ApJ, 283, 552

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

Frogel, J.A., Mould, J., Blanco, V.M. 1990, ApJ, 352, 96

Hughes, S.M.G., Wood, P.R. 1990, AJ, 99, 784

Ita, Y., et al. 2004, MNRAS, in press [astro-ph/0310083]

Lloyd Evans, T. 1980a, MNRAS, 193, 87

Lloyd Evans, T. 1980b, MNRAS, 193, 97

Nagayama, T., et al. 2003, SPIE 4841, 459

Noda, S., et al. 2002, MNRAS, 137

Persson, S.E., Murphy, D.C., Krzeminski, W., Roth, M., Rieke, M.J. 1998, AJ, 116, 2475

Schechter, P.L., Mateo, M., Saha, A. 1993, PASP, 105, 1342

Searle, L., Wilkinson, A., Bagnuolo, W.G. 1980, ApJ, 239, 803

Stellingwerf, R.F. 1978, ApJ, 224, 953

Tanabé, T., et al. 1997, Nature, 385, 509

Wood, P.R., et al. 1999, in IAU Symp. 191, Asymptotic Giant Branch Stars, ed. T. Le Bertre, A. Lèger & C. Waelkens (San Francisco: ASP), 151

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

Discussion

Feast: The large amplitude variable you showed in NGC 419 seems to show a long term variation characteristic of some C-Miras which are attributed to obscuration phase.

Tanabe: Thank you.

Handler: It would be astrophysically most interesting if your low-amplitude variables are indeed multimode pulsators. Can you already separate this hypothesis from (semi)regular variability?

Tanabe: No.

Toshihiko Tanabe and Masao Takata

https://doi.org/10.1017/S0252921100010824 Published online by Cambridge University Press