NEW M-TYPE VARIABLES IN GALACTIC DARK CLOUDS

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The results of the spectral classification of newly discovered M-type variables obtained as part of an H-alpha survey of Galactic dark cloud regions are presented. The survey was carried out with the 40" Schmidt camera of Byurakan Observatory, and the spectra of the variable stars for the classification were obtained with the Observatory's 2.6-m telescope. The observational material allowed register of late M-type variables as well as their brightness variations. Among the 97 newly discovered M-type stars, 22 show brightness variations. The results of the spectral classification of these new variables show that 21 out of 22 are red giants, and in all probability they are Mira Ceti type long period variables.

Keywords: *stars, variables, long period.*

1. Introduction

Long Period Variables (LPVs) are an important phase in the evolution of red giant and supergiant stars. Usually, their amplitudes in visible light are more than $2^m.5$ and their periods lie in the range of 100 to 1000 days. A large proportion of these are Mira Ceti stars. Usually, the absolute magnitudes of these stars in the Galaxy generally lie in the brightness range $M = -3^m.0$ to $-4^m.2$ [1]. Consequently, they represent one of the best distance indicators to galaxies, and are also useful in the study of Galactic structure.

Relatively little is known about the precursors of LPVs, and their masses and luminosities are not well determined. This is due to the fact that almost all Galactic LPVs are isolated members of the main field. Studies of the Galactic kinematics of LPVs show that they evolve from stars of typically $1.2\,M_{\odot}$ [2]. A few LPVs are known to be members of old globular clusters, and a few supergiant examples are known in very young open clusters. No large-amplitude LPVs are known to belong to clusters with a turn-off mass in the range $1-9\,M_{\odot}$. It is this range of stellar masses that mainly gives rise to the high mass loss rate AGB stars, such as Mira variables, OH/IR stars and dusty carbon stars, which are the major contributors of material to the interstellar medium [3]. In addition, the discovery and study of LPVs is very important in the investigation of the evolution of red giants and supergiants, particularly if we consider that they could be progenitors

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of planetary nebulae. The discovery of LPVs and their study in Galactic dark clouds (which are mainly known as young star forming regions, SFRs) are very significant.

An intensive survey of H_α objects in selected dark cloud regions of the Galaxy has been carried out at Byurakan Observatory over the last 10 years [4-8]. More than 200 new H_α objects have been discovered in six regions. As part of the H_α survey, late M-type giants have been discovered in three dark cloud regions. Variations of brightness have been detected for 22 out of 97 newly discovered red giants [9,10]. The preliminary results of the classification of 6 newly discovered variables have already been published [11], and the main results were reported at the IAU symposium 209 [12].

In this paper, the results of spectral classification of 21 newly discovered red variables in 3 Galactic dark cloud regions are presented.

2. Observations

The observations were performed with the 40" and 2.6-m telescopes of the Byurakan Observatory.

The 40" Schmidt camera was used in the discovery of these stars. The 4^o objective prism, RG1 and RG2 filters along with Kodak 103 aF, II aF and III aF photoemulsions were used during the observations. These combinations allowed the recording of the spectral region $\lambda\lambda 6000-7000\,Å$ .The limiting magnitude of these observations is about $17^m.0$ in red light. The dispersion of the obtained spectra was about $1100\,Å/\mu m$ near the Hα line. The observations were performed over a period of 10 years: in 1979, 1985 and 1989, which gave an excellent opportunity to follow the brightness changes of the stars during the above mentioned period. The method of discovering M giants is based on the detection of the two absorption bands of TiO, namely at $6158\,Å$ and $6651\,Å$. In this manner, 97 new M-type stars have been discovered in the total $48\,deg^2$. The method for discovering red giants and other details of these observations have been described and published previously [9].

The observational material for the spectral classification of the new variables was obtained with the 2.6-m telescope. Observations were carried out in 1999 and 2000. The "ByuFOSC" detecting system with the 1060×1028 pixel "Thomson" CCD, and red (spectral range 5450-7550 Å, dispersion 1.7Å/pixel) and green (spectral range 4350-6900Å, dispersion 2.7Å/pixel) prizms were used during the observations. The famous G-band, which is very important in the classification is outside the obtained spectral region.

A more detailed description of the telescope, detectors, and observational method employed was published in [13].

3. Results

The main results presented in this paper are the spectral classification of 21 new red variables, which were performed using two different methods of spectral classification.

It is well known that the spectra of stars of class M are, in general, characterized by the strong absorption bands of TiO, and also by the large number of metallic lines which block the spectrum of these stars at wavelengths shorter than $\lambda = 4000\,Å$. Different molecular bands such as CaH ($\lambda\lambda 6382$, 6389Å), MgH ($\lambda 5221\,Å$), CN ($\lambda\lambda 7945$, 8125, 8320Å), LaO ($\lambda\lambda 7403$, 7910Å), and VO ($\lambda\lambda 7000$, 7400, 7900, 8600Å) also exist in the spectra of M-type stars but are usually very weak, with only a few that can be used in their classification. Sometimes, these molecular bands can be used in the determination of their luminosity classes as well. In addition, it is worth noting that there are several telluric (O2) bands ($\lambda\lambda 6879$, 7600Å) and two large diffuse bands of watervapor ($\lambda\lambda 7190$, 8200Å). The existence of so many molecular bands strongly distorts the spectra of M-type stars, making their classification very difficult. In addition, it is doubtful that any late M-type star has a constant brightness. The variability of the brightness usually implies a variability in spectral type. These difficulties result in the classification of M-type stars showing a large scatter.

As already mentioned, the spectral region obtained with the 2.6-m telescope is 4350-7550Å. The spectral classification of the stars was performed using the spectral details existing in this spectral region.

For spectral class M0, the first bands of TiO at $\lambda\lambda 4954$, 5167 and 7054Å can be used for the classification of stars up to M3. For spectral classes M3-M5 the $\lambda\lambda 5759$Å and $\lambda\lambda 5810$Å bands of TiO are very useful in the classification. At M7 the bands of VO ($\lambda\lambda 5737$, 7373Å) become conspicuous and could be used in the classification as well. For stars with spectral classes later than M4, the CaOH ($\lambda 5500$Å) absorption band could play an important role. The latter with a part of the TiO absorption band ($\lambda 5446$Å) appears as a box-like absorption, whose red side becomes deeper in later types. For the determination of the spectral and luminosity classes of M-type stars, the intensity of the NaI doublet, as well as the depth of the different absorption bands, could also be used. These features show changes not only with the spectral classes but with the luminosity classes as well. In particular, the strength of the NaI doublet has a negative luminosity effect.

The method of quantitative spectral classification suggested more recently by Malyuto et al. [15] on the Galactic K-M stars has also been used. This method is based on the quantitative investigations of some of the most notable features of M type stars in the spectral region $\lambda\lambda 4800-7700$Å. One of the spectral ranges used is $\lambda\lambda 5839-6020$Å. The authors define as a measure of the strength of the feature the value of *I*, given by the equation [15]

$$I = 2.5\log(F_1 + F_3)/2F_2 . \quad (1)$$

Here, F_2 is the value of the mean flux of the central spectral range which includes the NaI doublet and the two TiO bands (5789-5839Å, 6020-6120Å). F_1 and F_3 are the values of the mean fluxes on both sides of the spectral region 5839-6020Å. In Fig.1, taken from [15], the areas A1 (5789-5839Å), A2 (5839-6020Å), and A3 (6020-6120Å) in the spectral region of NaID are illustrated. A good correlation has been found between *I* and the spectral types. In spite of the large scatter, it

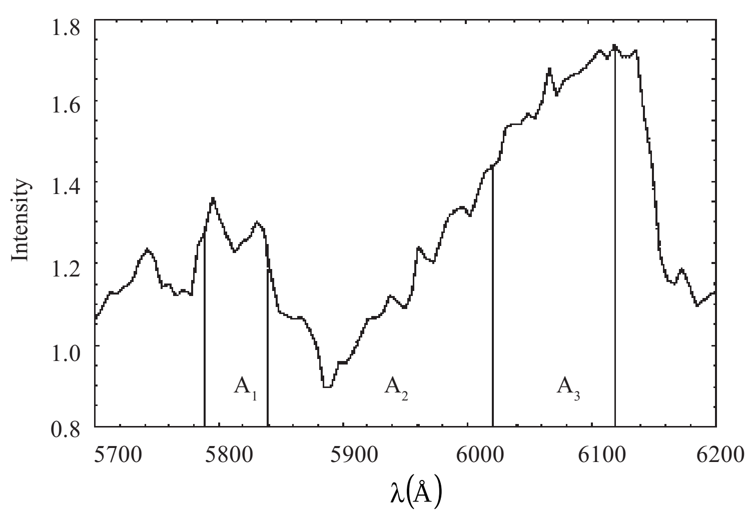

Fig.1. The spectral region near the NaD. A_2 is the central region with the NaI, *and* A_1 and A_3 are regions from both sides of the central region [15].

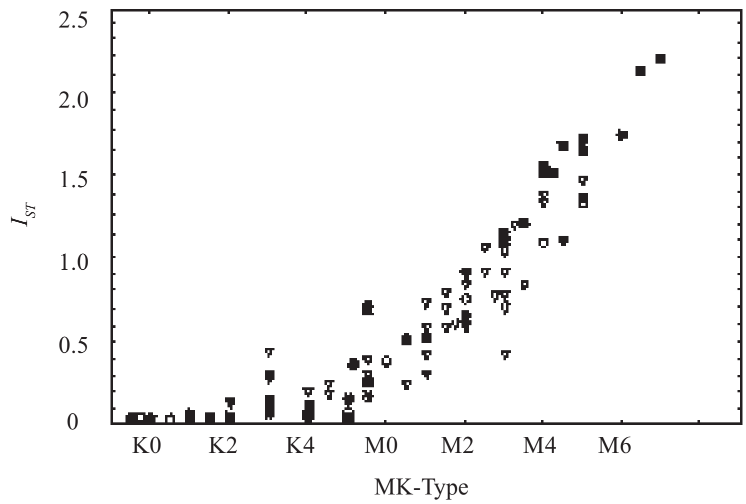

Fig.2. I_{ST} - MK diagram for Galactic disc stars taken from [15].

is seen that the higher values of *I* correspond to the later spectral classes. This correlation has been found for spectral classes up to M7 and, in all probability it continues further. The method used by Mulyato et al. [15] is based on the calculation of the spectral indices for 6 selected central spectral regions (4935-5090Å, 5150-5320Å, 5839-6020Å, 6143-6383Å, 6613-6832Å and 7060-7410Å). All the indices are very sensitive to temperature and only a few of them are also sensitive to luminosity. For determination of spectral types of the program stars the following central regions have been used (5839-6020 Å, 6143-6383 Å, 6613-6832 Å). We do not use the spectral indices in the determination of luminosity classes because of the very large scatter. Consequently, the quantitative method described by Malyuto et al. has been used in this paper in the determination of the spectral types only.

In Fig. 2 taken from [15] one can see the correlation between the MK spectral type and spectral indices I_{ST}. I_{ST} is

TABLE 1. Spectral Types of the Stars Determined by Two Different Methods

№	SP.(J)	SP.(M)	I_{ST}	№	SP.(J)	SP.(M)	I_{ST}
1	M5	M6	2.12	12	M4	M5	1.75
2	M6	M6	1.91	13	M5	M4	1.41
3	M6	M5	1.71	14	M6	M7	2.28
4	M7	M8	2.76	15	M6	M6	1.92
5	M4	M5	1.65	16	M4	M6	2.03
6	M4	M3	1.11	17	M3	M4	1.67
7	M5	M6	1.87	18	M3	M3	1.07
8	M5	M5	1.83	19	M6	M7	2.51
9	M5	M4	1.52	20	M6	M5	1.55
10	M5	M4	1.47	21	M7	M7	2.26
11	M4	M3	1.21				

the sum of 3 calculated indices ($I_1+I_2+I_3$) corresponding to the three different above-mentioned spectral regions. A large scatter can be seen in Fig. 2 and for the same spectral index we could have a difference of one subclass in the spectral type. It has been pointed out in [15] that such a scatter could be a result of different luminosities, as well as by the brightness variation of the stars. As one can see in Fig. 2, the dependence between MK spectral type and I_{ST} spectral indices is sensitive starting from K4 spectral type only.

In the same way as described by Malyuto et al. [15] we have calculated the spectral indices for the above-mentioned 3 spectral regions. These spectral indices are mainly sensitive to the spectral types of the stars. The spectral indices I_1, I_2, and I_3 for all 21 variable stars have been calculated, and the obtained spectral indices for each star have been added together ($I_{ST}=I_1+ I_2+I_3$) [15]. This is more sensitive to the spectral class. Using the values of the obtained spectral index I_{ST} and the correlation between I_{ST}-MK type, the spectral classes of the investigated 21 variable stars have been determined.

In Table 1 the spectral classes of the stars determined by two different methods [14,15] and the values of I_{ST} for each star are presented. The comparison of the spectral types determined by different methods can be seen in Fig. 3. The large scatter is evident.

The spectral classes presented in Table 2 for each star are the mean values taken from the correlation shown in Fig. 1. We have to point out that the large scatter in Fig.3 particularly is a result of the variability of the stars.

TABLE 2. Observational Data of Red Variables

№	α_{2000}	δ_{2000}	R_{min}	R_{max}	ΔR	Sp	I_{H_α}	IRAS No.
1	$20^h47^m27^s.0$	53°27'37"	$14^m.8$	$12^m.8$	$2^m.0$	M5III	*n*	
2	20 49 50.2	53 52 46	13.5	12.8	0.7	M6III	*n*	20483+5358
3	20 52 32.7	53 26 25	13.6	12.8	0.8	M6III	*n*	20510+5314
4	20 52 47.9	53 02 29	13.3	12.4	0.9	M7III	*w*	20513+5251
5	20 56 08.3	55 50 38	12.3	11.6	0.7	M4IV	*n*	
6	20 57 46.1	55 07 13	12.6	11.9	0.7	M4IV	*n*	20563+5455
7	20 58 48.5	53 42 05	12.9	12.4	0.5	M5III	*m*	
8	20 59 08.1	55 42 41	15.2	14.2	1.0	M5III	*w*	20577+5530
9	21 02 51.1	54 43 56	13.0	12.4	0.6	M5III	*n*	21014+5432
10	21 09 16.3	54 56 12	11.1	10.5	0.6	M4III	*n*	
11	21 24 34.3	56 10 37	13.7	12.5	1.2	M4III	*w*	
12	21 34 09.8	55 35 17	10.9	10.3	0.6	M5III	*m*	
13	21 36 39.2	54 11 28	12.8	12.2	0.6	M4III	*n*	21349+5357
14	21 36 37.8	57 00 57	13.3	12.5	0.8	M6III	*w*	
15	21 39 27.6	56 17 13	12.6	11.9	0.7	M6III	*m*	21378+5603
16	21 39 53.7	54 44 43	9.1	8.3	0.8	M5II	*w*	
17	21 42 08.9	54 58 04	12.7	12.2	0.5	M3III	*n*	
18	21 46 26.3	55 07 45	12.8	12.2	0.6	M3III	*w*	
19	23 29 32.1	64 51 27	13.0	12.2	0.8	M6III	*n*	
20	23 52 59.0	64 20 26	12.3	11.6	0.7	M6III	*w*	
21	23 53 30.5	63 48 48	12.8	12.2	0.6	M7III	*n*	

n - no emission; *w* - weak emission; *m* - middle strength emission.

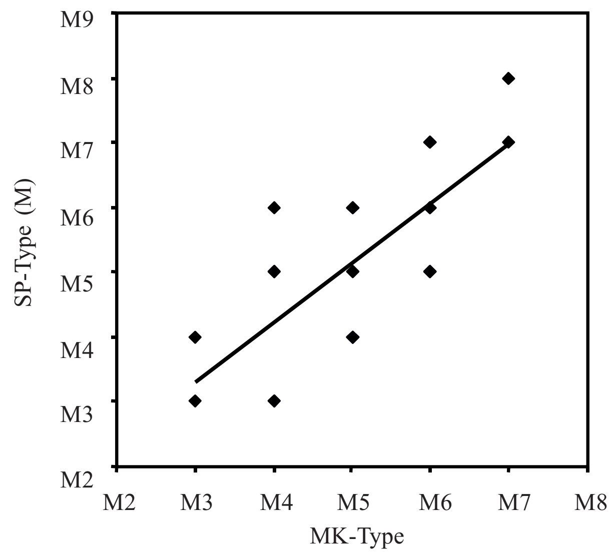

Fig.3. Correlation between MK spectral types determined by 2 different methods.

Fig. 4 presents the correlation between spectral index I_{ST} and spectral types for the 21 program stars. As one can see, inspite of the large scatter, a real dependence exists.

The classification of the programme stars has been carried out using the method described by Jaschek and Jaschek [14], as well as the method suggested by Mulyato et al. [15]. For the determination of the luminosity classes, the behavior of the strength of the NaI doublet, as well as the strengths of the CaH ($\lambda\lambda 6382$, 6389Å), MgH ($\lambda\lambda 4780$, 5221Å), and other molecular bands which are sensitive to the luminosity classes of these stars, have been used. All of these features have been used in the determination of the luminosity classes, which is well described by Jaschek and Jaschek [14].

The results of the classification of 21 stars are presented in Table 2. The coordinates (J2000.0), observed magnitudes, the detected amplitudes (ΔR) in red light, and the identification with sources in the IRAS catalogue are presented. The

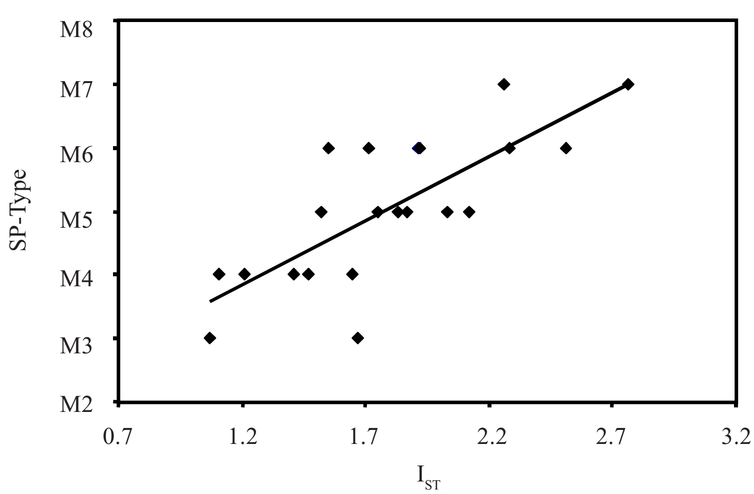

Fig.4. The spectral indices I_{ST} are plotted against the determined MK spectral types.

relative intensity of the Hα emission line, is given also. For the estimation of the relative intensity of the Hα emission line the observational material obtained with the 40" Schmidt camera as well as the spectra obtained with the 2.6-m telescope have been used. The spectral types presented in Table 2 for each star are the average of the values obtained by the two different methods [14,15].

The results of the spectral classification using the two above-mentioned methods agree very closely with each other, in spite of the difference in one subclass. If the first method [14] could be used only with the very detailed study of the obtained spectra, the method of the quantitative spectral classification [15] will make the first step of the classification much easier.

4. Conclusion

As it can be seen in Table 2, the spectra of 10 variable stars show the Hα emission with different intensities. This is good evidence for chromospheric activity on the stars. It is worth noting that the detected Hα emissions on these stars show intensity changes, which is one of the important characteristics of LPVs. The second interesting fact is that 8 of the 21 variables are identified with previously known infrared sources. Finally, 18 variables out of 21 are situated in, or near, the association Cyg OB7, where on the basis of the same observational material, more than 40 new Hα objects [6,7] and, more recently, 3 groups of HH objects [16,17] have been discovered. As can be seen, the discovered variables lie in the spectral range M3-M7 and their luminosity classes are from II to IV.

The results of the spectral classification show that 21 out of the discovered 22 variables are red giants. The amplitudes of their brightness variation lie in the range $0^m.5 - 2^m.0$ in the red band of the spectrum. These amplitudes of brightness variations are close to the long-period variables with low amplitudes discovered in the Magellanic Clouds [18], and to the amplitudes of OH/IR and dusty carbon stars in the Galaxy. It is important to point out that in the Magellanic Clouds some long period variables have been detected with amplitudes of $0^m.1$ in the near *I* band of the spectrum [18]. The further study of the physical characteristics of these stars is considered to be very important.

The majority of these stars are situated in the association Cyg OB7 and some of them in all probability are projected on the dark cloud Khavtassi 141 [19]. The view that LPVs are progenitors of planetary nebulae makes the further study of these newly discovered stars very important since we'll be able to estimate their distances with very high accuracy and this could give us the possibility of accurate estimation of the absolute magnitudes, which is very important in the case of long-period variables.

To summarize the results of the present observations, we have to point out the following: the classification of 21 new variable stars has been performed using two different methods. All the characteristics of these stars show that to all probability they are Mira Ceti type long-period variables. It is very important also that they are situated in the star forming region in Cygni and may be either projected onto the region of the dark cloud KH 141 or embedded in this cloud.

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