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DISTRIBUTION OF CARBON STARS IN THE GALAXY

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ABSTRACT. A search for new faint carbon (C) stars in the Polar region $\delta > 55^o$ has been accomplished by obtaining objective prism spectra in the visual and near infrared 550 -- 900 nm on images of CCD camera of Baldone Schmidt telescope of Astrophysical observatory of University of Latvia obtained from May 2006 till June 2015. The positions of stars having color indices (J – K) > 1.3 mag were selected in Two Micron All Sky Infrared Survey – 2MASS to pick out potential carbon stars.

Our survey is limited in brightness by J < 10 mag. Identification of observed lines and molecular bands in mentioned region are given. The comparison of low resolution spectra of M, C and Zr-type stars are given.

24 new carbon stars were found. Using distribution of absolute magnitudes of carbon stars in Large Magellanic Cloud (LMC) was evaluated the M_k for newly discovered C stars. Various spectral gradients of carbon stars with known effective temperatures obtained by other methods are studied, and a correlation is found between Teff and the spectral gradient [757 – 685]. The accuracy of effective temperature is ± 350 K. The interstellar absorption was calculated from reddening, which is taken from infrared full-sky dust maps. Such characteristics as true color index $(J – K)_0$, effective temperature T_{eff}, distance from the Sun in kpc, absolute magnitude M_k, bolometric magnitude, were obtained for newly discovered carbon stars. The accuracy of distances is small and mainly depends on dispersion of M_k in LMC and reaches 30%.

Keywords: circumstellar mater, near infrared, carbon stars, absolute magnitude, distance

АБСТРАКТ. Пошук нових слабких вуглецевих (С) зорь в Полярній області $\delta > 55^o$ був досягнутий шляхом отримання спектрів з об'єктивною призмою в області візуального і ближнього інфрачервоного випромінювання в діапазоні 550-900 нм на зображеннях ПЗЗ-камери телескопа Шмідта Астрофізичної обсерваторії Університету Латвії в Балдоне, які були отримані з травня 2006 року по червень 2015 року. Позиції зорь з кольоровими індексами (J – K) > 1,3 були відібрані, використовуючи дво-мікрохвильовий інфрачервоний обзор всього неба (2MASS) для виявлення потенційних кандидатів вуглецевих зорь.

Наш огляд обмежений яскравістю в системі J < 10 mag. Приведена ідентифікація спостережуваних ліній і молекулярних смуг у вказаній області спектру. Дано порівняння спектрів зорь спектральних класів M, C і Zr низької роздільної здатності.

Було виявлено 24 нові вуглецеві зорі. Використовуючи розподіл абсолютних величин вуглецевих зорь у Великій Магеллановій Хмарі (LMC), була оцінена M_k для знов відкритих С-зорь. Досліджуються різні спектральні градієнти вуглецевих зорь з відомими ефективними температурами, отриманими іншими методами, виявлений кореляційний зв'язок між T_{eff} і спектральним градієнтом [757 – 685]. Точність визначення ефективної температури, використовуючи знайдену кореляцію, складає ± 350 К. Міжзоряне поглинання розраховувалося по почервонінню, яке запозичене з інфрачервоного огляду пилевих хмар Галактики. Для знов виявлених вуглецевих зорь були отримані такі характеристики, як дійсний індекс кольору $(J – K)_0$, ефективна температура T_{eff}, відстань від Сонця в kpc, абсолютна світність M_k, болометрична величина. Точність відстаней маленька і в основному залежить від дисперсії M_k в LMC і досягає 30%.

Ключові слова: межзоряна матерія, ближній інфрачервоний діапазон, вуглецеві зірки, абсолютна зоряна величина, відстань

1. Introduction

Carbon stars (C) – one of the reddest stars in the sky – since the fifties of the previous century attract great attention of astronomers. Considerable efforts have been devoted to discover distant and faint carbon stars in the Galaxy. Carbon stars are interesting not only from the stellar evolution point of view, but as it has been revealed in the first summarizing studies they also delineate the spiral structure of the Galaxy. The results of searches do-nen till now are summed up in the General Catalogue of Cool Carbon Stars (CGCS) (Alksnis et al., 2001) contain-ing 6991 entries. Most of the findings have been made using objective prism spectra recorded on photographic plates in the visual spectral region with wide field tele-scopes. The distinguishing indication of C stars is the presence of the Swan band system of the C2 in the spectra. However, the search could be done more efficiently in the near infrared region where the radiation maximum of carbon stars is localized and fainter objects come in reach. The pioneering investigation in this direc-tion has been made by Nassau & Velghe (1964) who reached the wavelength of 880 nm.

A new perspective in the carbon stars spectrophotometry at low resolution opens by using CCD's – they have more sensitivity than photoplates, giving possibilities of quantitative measurement of spectral details and reaching further in the infrared region. However, a serious drawback is a reduction of the available field area. Searching for new carbon stars may overcome this obstacle using the 2MASS catalogue by Skrutskie et al. (2006) containing J, H, and K magnitudes for thousands of very faint red stars.

Comparing the catalogued carbon stars in CGCS with 2MASS survey shows that (except few infrared objects) they are mostly objects brighter than J = 8.5 mag. Our intention is to encompass fainter objects. We take objec-tive prism spectra with the CCD camera of all northern sky 2MASS objects brighter than J = 10 mag with (J – K) > 1.5 mag, to check which of them may be new cool carbon stars. The limit on (J – K) is chosen, to exclude prevalent numerous early M–type stars. As it is shown in article by Dzervitis and Eglitis (2005), where color index distribution of known carbon stars has been analyzed, approximately this J – K value is the boundary in which cool carbon stars come in light. In some regions of the sky the bound on (J – K) is reduced to 1.3 mag to check the previous statement. A range of 550 nm – 900 nm, where carbon stars are brighter than in blue, has been used for the search.

2. Observations

Observations were made with Schmidt system tele-scope (240 x 120 x 80 cm) of Baldone Astrophysical ob-servatory with a four degrees objective prism and CCD ST – 10XME (2184 x 1472 pixels; size of pixel is 6,8 x 6,8 μ). The spectral range extends from 550 to 900 nm with a spectral resolution of about 500 and maximum sensitivity of the system at 650 nm. Observations were made from May 2006 till June 2015. At first we chose high declina-tion fields which are rarely populated by stars. Observa-tion fields are chosen to the north from δ > 60o. Observa-tion list contains more than 2000 stars from 2MASS with indices (J – K) greater than 1.3 mag and with J magnitude mainly brighter than 10 mag.

2.1. Spectral features of the late stars in 550 nm – 900 nm

Due to a low atmospheric temperature of cool red stars their objective prism spectra main details are molecular bands originated from transitions from the lowest electron levels of molecules. Discrimination among the three spectral types of cool giant stars – M, S and C is based on the fact that the main discriminating molecular bands in their spectra in each case belong to different molecular species and thus are located at different wavelengths. Hence, a characteristic spectral pattern is formed.

Bands seen in carbon star spectra mainly belong to the CN molecule red system excepting the earth atmospheric O2 A band (approximately at 765 nm) which unlike M and S types happens to lay outside from stellar molecular bands and is therefore distinctly seen as an isolated spectral feature. Visible band sets of the red CN system originated from transitions between vibration levels with quantum number difference Δ ν = +2, +3, +4, where in each set +3, +4 the reddest overlapping bands are evident with heads as indicated in Table 1. The first column of table contains absorbing molecule and band system designation, the second – quantum number difference, the third – band head assignment and then subsequently wavelength of correspon-ding band head follows.

In total the late C star spectrum consists of symmetric pattern with atmospheric O2 band in the centre enclosed by two band sets of CN molecules. From the red side spectra is shortened by abrupt termination of very strong CN (0.1) band head at 914 nm and from the blue side it is usually depressed by C_2 of Swan band head (0,1) at 564 nm. From atomic lines only Na I doublet in the blue part and Ca II triplet in the red part sometimes are seen as faint details in spectra of C stars.

Spectra of M-type stars are dominated by triplet γ and γ' system bands of the titan oxide (TiO), forming a very specific pattern of isolated bands. In addition at the red side of singlet δ, ε bands are also visible. Late M-type spectra involve bands of the vanadium oxide molecule but they overlap with TiO bands and can't be seen as separate details. Just O2 atmospheric A band coincides with TiO γ system Δν = -1 band.

Table 1: Atomic lines and molecular bands seen in low resolution carbon star spectra

Band	Δ\ν	ν', ν"	λ (nm)
CaII, CaII	blend		852
CaII			866
NaI doublet	blend		589
CN red system	b.h. +2	(2,0)	790
CN red system	b.h. +2	(3,1)	809
CN red system	b.h. +2	(4,2)	830
CN red system	b.h. +3	(3,0)	694
CN red system	b.h. +3	(4,1)	711
CN red system	b.h. +3	(5,2)	728
CN red system	b.h. +3	(6,3)	745
CN red system	b.h. +4	(5,1)	635
CN red system	b.h. +4	(6,2)	649
CN red system	b.h. +4	(7,3)	665
C_2 Swan band	b.h. -1	(0,1)	564
O_2 atmospheric	A band		765

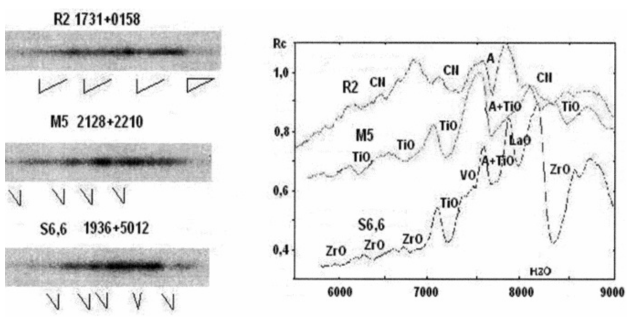

Figure 1: Comparing the spectra of C–type star BL Ori (at the bottom; axis of intensity shifted by -0.1), M–type star M3III $18^h11^m36^s$ $+56^o52'$ 38" (2000) (at the top; axis of intensity shifted by +0.3) and S–type star CCS 1053=V530 Lyr (in the middle). The left panel present objective prism spectra of same stars obtained in Baldone.

S star spectra are similar to M type. The difference lies in some spectral details – bands originated between two lowest level transition of zirconium oxide at 649 nm and at 585 nm, and lanthanum oxide band at 788 nm. Other LaO band at 737 nm overlaps with atmospheric A band.

Examples of all three type of stars are presented in Fig. 1.

3. Some characteristics of discovered carbon stars

2.1. Effective temperatures

Bergeat et al. (2001} gives the new effective temperature scale for late carbon stars which statistically is in a good agreement with the sample of directly determined temperature values from the observed angular diameters and with temperature estimates from the infrared flux method. Since the study is broad and covers 390 C stars, it was possible to check whether the effective temperature scale is used in the case of low resolution. At Baldone observatory it is possible to observe 191 carbon stars of Bergeat et al. (2001) list. Other Bergeat's stars were situated in the sky too low to be seen in Baldone.

Spectra was normalized to the most intensive point of spectrum (usually 783 nm) to make a comparison of the spectrophotometric gradients of various stars.

Spectrophotometric gradients: [685 – 575], [757 – 685], [775 – 685], [775 – 885] were correlated with the effective temperatures from Bergeat's list). Only gradient [757 – 685] shows the correlation with T_{eff} (see Fig. 2). and is confirmed for 191 bright carbon stars. It reveals possibility to classify carbon stars by temperature indices and to detect effective temperatures of stars with accuracy ± 350 K at spectral resolution 500.

2.2. Interstellar absorption

Magnitudes and colour indices have been corrected for interstellar extinction and reddening.

The interstellar absorption A_k and $(J – K)_0$ can be calculated from interstellar reddening. $A_k = 0.302E(B-V)$ and $(J – K)_0 = (J – K) – 0.405E(B-V)$, where $E(B – V)$ is taken from infrared full-sky dust maps obtained by Schlafly and Finkbeiner (2011**)** **.**

2.3. Distances

Our chosen absolute magnitudes of carbon stars are based on the investigations of C stars in LMC. Mauron (2008) showed that absolute magnitude of late carbon stars vary in a small range of magnitude from -8.1 to -7.4 depending on $(J – K)_0$ color indices. Correlation bet-ween $(J – K)_0$ color indices and absolute magnitude M_k in LMC were used in this paper to obtain this value for discovered C stars.

The distance r was calculated from the equation:

$$M_k – m_k + 5\lg r + A_k + 10 = 0,$$

where r in kpc.

The distances r are evaluated taking absolute magnitudes from relation between M_k and $(J – K)_0$ given by Mauron (2008) using calculated $(J – K)_0$ for discovered carbon stars. Results of obtained characteristics are collected in Table 2.

2.3. Bolometric magnitudes

Bolometric magnitudes are derived by equation:

$$M_{bol} = M_k + BC$$

Correlation between bolometric correction between BC and $(J – K)_0$ is presented in paper by Gullieuszik et al. (2012). He showed that BC is weakly depends on colour index $(J – K)_0$ for late type C stars. This correction is used for the acquisition of the M_{bol}.

4. Conclusion

24 new carbon stars (numbered as BIC) have been found at declinations greater than 55°. Carbon stars discovered in Baldone have temperatures in range between 1840 K and 3630 K. Distances till them are between 2.8 kpc and 7.9 kpc. According to distances and galactic latitudes they are located in Orion and Perseus arms. Three of stars BIC 7, BIC 11 and BIC 13 are located 13.3 kpc, 13.2 kpc and 16.1 kpc away, much further away than the outer arm of Galaxy. If we assume that the metallicity in our Galaxy and the Sgr subgalaxy is similar, then the absolute

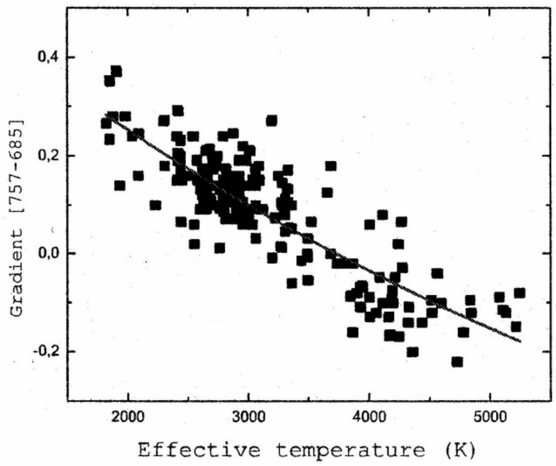

Figure 2: Relation between effective temperatures (Bergeat et al. 2001) and spectrophotometric gradient [757 – 685] obtained from low resolution spectra.

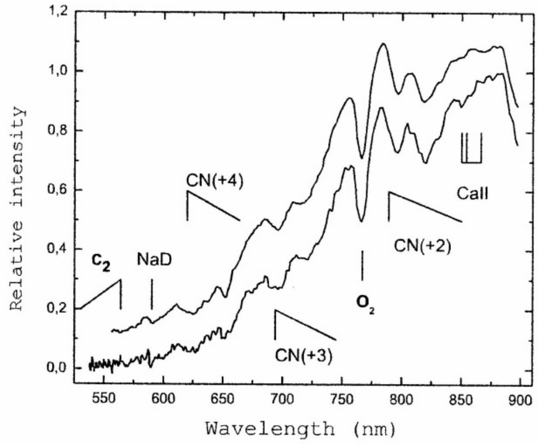

Figure 3: Spectra of discovered carbon star BIC 15 (at the bottom) and BIC 16 (at the top; gradient axis shifted by +0.1)

Table 2: Characteristics of carbon stars discovered in Baldone

Designation	α (2000)	δ (2000)	K	$(J-K)_0$	E(B – V)	M_k	r (kps)	T_{eff}	M_{bol}
BIC 14	001336.30	+652710.2	6.54	1.61	1.78	-8.02	6.39	2230	-5.02
BIC 1	003627.38	+654014.1	6.59	1.35	1.89	-7.65	5.47	2300	-4.75
BIC 15	010028.67	+661639,.8	5.91	1.38	1.79	-7.70	4.12	1920:	-4.80
BIC 2	013348.57	+702623.5	6.61	1.72	0.52	-8.14	8.28	2260	-5.14
BIC 3	031829.28	+653820.9	6.63	1.29	1.09	-7.54	5.86	2410	-4.64
BIC 4	040949.55	+664155.1	5.80	1.78	0.61	-8.16	5.68	2410	-5.16
BIC 5	210522.23	+780116.2	6.12	3.47	0.48	-7.55	5.06	2560	-3.75
BIC 6	213542.71	+683907.1	4.91	3.35	0.91	-7.59	2.79	2170	-3.79
BIC 7	214149.53	+663409.9	7.74	1.02	0.46	-6.71	7.27	3630	-4.01
BIC 8	214446.47	+662710.8	6.71	1.30	0.69	-7.56	6.49	2970	-4.66
BIC 9	215304.85	+650210.2	5.68	1.94	0.72	-8.14	5.25	2170	-4.94
BIC 10	215413.43	+683511.4	6.76	1.63	0.31	-8.05	8.78	3020	-5.05
BIC 11	221138.04	+782812.6	8.07	2.22	0.36	-8.02	15.7	3070	-4.82
BIC 12	230801.05	+801016.7	7.66	2.38	0.13	-7.90	13.1	2560	-4.70
BIC 16	233958.74	+632054.7	6.51	1.40	1.26	-7.75	2.0	1840:	-4.85
BIC 12	235742.23	+690134.0	5.31	2.93	0.99	-7.97	4.0	2200	-4.97
BIC 17	205607,40	+564156,8	7.96	2.16	0.08	-8.04	15.7	2230	-4.84
BIC 18	205710,47	+542811,0	4.09	2.03	2.17	-8.09	2.0	1969	-4.89
BIC 19	205814,90	+552342,6	5.39	1.80	0.06	-8.16	5.1	2197	-5.06
BIC 20	205820,97	+555808,9	9.16	1.19	0.06	-7.33	19.7	3168	4.53
BIC 21	210108,27	+552140,7	7.87	1.08	0.21	-6.94	8.9	2197	4.14
BIC 22	232939,07	+650337,9	6.49	3.31	0.06	-7.61	6.5	1994	-4.71
BIC 23	234142,94	+624202,3	7.25	1.72	0.03	-8.14	11.9	2263	-5.24
BIC 24	234226,63	+624401,3	5.71	1.84	1.80	-8.16	4.6	2298	-5.26

magnitude of C stars which we calculated using M_k distribution LMC should be reduced by 0.5 mag (Mauron 2008). Than distances which are given in Table 2 should be redused by 20 percent for nearer C stars and by 26 percent for further C stars.

Two of discovered stars BIC 15, BIC 16 (Fig. 3), BIC 18 and BIC 22 have largest gradients and accordingly lowest temperatures. Whereas C stars BIC 7, BIC 10, BIC 11 and BIC 20 have smallest gradients and highest temperatures.

The errors for distances mainly depend on error of evaluation of absolute magnitude and can be obtained by equation:

$$\sigma = \pm \sqrt{\left(\frac{dr}{dM}\right)^2 + \left(\frac{dr}{dK}\right)^2 + \left(\frac{dr}{dE(B-V)}\right)^2}$$

As follow from Mauron (2008) paper the everage error of absolute magnitude is close to ± 0.4 mag. It means that error of distances are close to 30%.

Its important is checking of our methodology comparing to distances obtained with other methods. For example using relation between absolute magnitudes and period of light variability or using GAIA parallax measurements.

Future investigations are associated with increasing of accuracy of absolute magnitude determination.

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