DISTRIBUTION OF CARBON STARS IN THE GALAXY

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ABSTRACT. A search for new faint carbon (C) stars in the Polar region δ > 55° 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 Mₜ 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 has been accomplished by obtaining objective prism spectra recorded on photographic plates in the visual spectral region with wide field telescopes. The distribution of carbon stars in Large Magellanic Cloud (LMC) was evaluated the Mₜ, absolute magnitude Mₖ, and fainter objects come in reach. The pioneering investigation 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.

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

ABSTRACT. Пошук нових слабких вуглецевих (C) зорь в Полярній області δ > 55° 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 відібрани, 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 Mₜ для знов відкритих C-зорь. Досліджуються різні спектральні градієнти вуглецевих зорь з відомими ефективними температурами, отриманими іншими методами, виявлений кореляційний зв’язок між Teff і спектральним градієнтом [757 – 685]. Точність визначення ефективної температури, використовуючи знайдену кореляцію, складає ± 350 К. Міжзоряне поглинання розраховувалося по почервоненню, яке запозичене з інфрачервоного огляду пилевих хмара Галактики. Для знов виявлених вуглецевих зорь були отримані такі характеристики, як дійсний індекс кольору (J – K)ₚ, ефективна температура T eff, відстань від Сонця в крс, абсолютна світність Mₖ, болометрична величина. Точність відстаней маленька і в основному залежить від дисперсії Mₜ 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) containing 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 direction has been made by Nassau & Velghe (1964) who reached the wavelength of 880 nm.

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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 object-ive 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 Egliitis (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 telescope (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST – 10XME (240 x 120 x 80 cm) of Baldone Astrophysical 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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 $T_{\text{eff}}$ (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 $\pm 350$ 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 between $(J – K)_0$ 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:

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

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:

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

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 $M_{\text{bol}}$.

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
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) | $T_{\text{eff}}$ | $M_{\text{bol}}$ |
|-------------|----------|----------|---|-------------|----------|-------|--------|--------------|--------------|
| 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 |

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

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

As follow from Mauron (2008) paper the average error of absolute magnitude is close to ± 0.4 mag. It means that error of distances are close to 30%. The 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 reduced by 20 percent for nearer C stars and by 26 percent for further C stars.
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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