АСТРОФИЗИКА

ТОМ 57 НОЯБРЬ, 2014 ВЫПУСК 4

INVESTIGATION OF FAINT GALACTIC CARBON STARS FROM THE FIRST BYURAKAN SPECTRAL SKY SURVEY. OPTICAL VARIABILITY. I. N-TYPE AGB CARBON STARS. K-BAND ABSOLUTE MAGNITUDES AND DISTANCES

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Reseived 14 May 2014
Accepted 19 September 2014

The goal of this paper is to present the optical variability study of the comparatively faint carbon (C) stars which have been discovered by searching the First Byurakan Survey (FBS) low-resolution (lr) spectral plates at high Galactic latitudes using a recent wide-area variability databases. The light curves from the Catalina Sky Survey (CSS) and Northern Sky Variability Survey (NSVS) databases were exploited to study the variability nature of them. In this paper, first in this series, the variability classes are presented for 54 N-type Asymptotic Giant Branch (AGB) C stars. One find that 9 stars belongs to the group of Mira-type, 43 are Semi-Regular (SR), and 2 stars are Irregular (Irr)-type variables. The variability types of 27 objects has been established for the first time. K-band absolute magnitudes, distances, and height from the Galactic plane were estimated for all of them. We aim to better understand the nature of the selected C stars through spectroscopy, 2MASS photometric colours, and variability data. Most of the tools used in this study are developed in the frame of the Astronomical Virtual Observatory.

Key words: *stars: N-type AGB stars: variability: K-band luminosity: distances*

1. *Introduction*. Variability is an important phenomenon in astrophysical studies of evolution and structure, both stellar and Galactic and extragalactic. Particularly, faint stellar populations in the Galactic Halo carry information on numerous characteristics and formation mechanisms and subsequent evolution of the Galaxy. Some type of variable stars, such as RR Lyrae stars, Cepheids, are an excellent tool for studying the Galaxy. Being nearly standard candles (as a distance determination indicators) and being intrinsically bright, they are a particularly suitable tracer of Galactic structure [1-3]. Large-amplitude ($\Delta V > 2.5$) Asymptotic Giant Branch (AGB) Mira-type variables (Miras) are also very important distance indicators for old and intermediate age populations [4].

Cool, luminous N-type AGB variable carbon (C) stars have been the subject of many studies [5]. Part of them follow Period-Luminosity (PL) relations and are also using for investigating the global properties of the galaxies. Moreover, in the focus of many researchers in last two decades are the Faint High Latitude Carbon Stars (FHLCs, $R>13$ mag). Particularly, very distant and faint N-type objects are the subjects of the intensive studies for the kinematics and chemical composition of the Halo of Galaxy [6-9], also in the Local Group of Galaxies [10-13].

Despite the importance of variability, the variable optical sky remains largely unexplored and poorly quantified, especially at the faint end ($V>15$ mag). Numerous questions remain still unanswered, particularly; what degree do different variable populations contribute to the overall variability, how are they distributed in magnitude and color, and what are the characteristic time-scales and dominant mechanisms of variability. To answer these questions, several contemporary projects were started which aimed at regular monitoring of the optical sky.

In this paper (first in this series) we report the results on optical variability study of the 54 cool N-type AGB FBS (First Byurakan Survey-FBS) [14] C stars (out of 120, where 66 objects show early C-type stars characteristics, i.e. they are R, CH, and dwarf C stars (dC)) detected on the FBS plates, using the two most prominent wide-area variability databases to derive some of their important characteristics. The C-rich nature was confirmed for all of them by moderate-resolution CCD spectrosopy [15-18].

2. *FBS Late-Type Stars Catalogue*. The 54 N-type C stars studied in this paper are included in the "Revised And Updated Catalogue Of The First Byurakan Survey of Late-Type Stars" (LTSs) [19], which contains photometric data for 1045 objects. The details of the selection and classification of the FBS LTSs, as well as the spectroscopic observations are described in paper [19].

Since 2007, all the FBS spectral plates are digitized and the Digitized First Byurakan Survey (DFBS) database is publicly available [20]. With the help of standard image analysis softwares, the DFBS plates are studied for faint LTSs close to the detection limit in each plate. As a result additional 24 new FHLC stars and numerous of M-type stars of late subclasses are detected (the total number of C stars detected is 120). The data about new detected DFBS C stars are presented in papers [21,22].

3. *Variability Databases Used*. To study optical variability for 54 N-type C stars the basic data coming from the two most prominent and wide-area sky surveys (as a two supplementary databases for the FBS LTSs) was used and considered; the Northern Sky Variability Survey (NSVS) which is based on ROTSE-I (Robotic Optical Transient Search Experiment) and the Catalina Sky Survey (CSS).

3.1. *ROTSE-I* experiment [23] monitored the entire observable sky twice a night from $V=\sim 8.0$ to a limit of $V=\sim 15.5$ mag. The NSVS [24] is based on data from the ROTSE-I (the effective wavelength is that of the R band)

and contains light curves for about 14 million of objects, with $100 \div 500$ measurements per object collected over one year (light curves is available at http://skydot.lanl.gov/nsvs/nsvs.php/). A catalog of 8678 slowly varying stars ("Red Variables in the NSVS") with near-infrared (NIR) colours corresponding to the evolved AGB population are presented by authors of paper [25]. Identification and classification of 4659 objects into several variable star classes in NSVS, is given in paper [26] also.

3.2. *The Catalina Surveys*, which consists of Catalina Sky Survey (CSS) and the Catalina Real-Time Transient Survey(CRTS, a consortium of two cooperating surveys, the original Catalina Sky Survey (CSS) and the Mt. Lemmon Survey (MLS)) [27]. The CSS project involves searches for rapidly moving Near Earth Objects (NEOs), while CRTS searches for stationary optical transients (OTS, http://nesssi.cacr.caltech.edu/DataRelease/). Both surveys work collaboratively from data from three telescopes operated by CSS, the Catalina Schmidt telescope, the 60" Cassegrain reflector operated by the Steward Observatory (MLS), and the 0.5m Schmidt telescope of the Siding Spring Observatory (Siding Spring Survey - SSS). This data release encompasses the photometry for 500 million of objects (~40 billion measurements) with *V* magnitudes between 11.5 and 21.5 from area of 33000 square degrees, presently. Note that, for complement, the AAVSO (American Association of Variable Star Observers, site at http://www.aavso.org/), and the LINEAR (Lincoln Near - Earth Asteroid Research) [28] (http://skydot.lanl.gov/linear/linear.php/) databases were also investigated. In LINEAR database we found observations for FBS 0910+197 only.

4. *Light Curve Analysis, Period Determination And Classification*. The CSS and NSVS phase dependence light curves are analysed to study the variability nature of the 54 N-type C stars. In NSVS database the plots are not available for two stars only, namely FBS 0158+095, and FBS 1502+359, while 27 objects out of 54 have been classified in NSVS catalogue [25]. The field of 13 FBS N stars is not yet covered by CSS data, while the imput declinations of 6 Objects is beyond the CSS survey area. For a main parameters estimation, a CSS survey phase dependence light curve was used as a basic, which is more deeper and is a long-term monitoring than NSVS (the one year time span of NSVS makes it difficult in numerous cases to estimate amplitudes and periods precisely). In some cases, when light curves is absent in CSS, the NSVS light curve are analysed. Phase dependent light curve analysis and variability type classification was peformed with help of VStar Software (a multi-platform data visualization and analysis tool, available at http://www.aavso.org/). VStar implements the Date Compensated Discrete Fourier Transform (DCDFT) algorithm [29] to get the basic pulsation period.

For numerous of N-type stars from the "General Catalogue Of Galactic

Carbon Stars" [30] the NSVS phase dependence light curves are considered also, which are classified in [25] as Mira variables. All they show amplitude of variability in R band larger than 1.5 mag. In CSS database we accept as a Mira-type variables for which $\Delta V \geq 2.5$.

The light curve analysis resulted to confirm for 9 stars as Mira-type variables, 43 as Semi-Regulars (SR) with very well expressed periodicity, and 2 objects as a Irregular (Irr)-type variables. The variability types of 27 stars are presented for the first time. Moreover, the pulsation periods of 27 objects classified in NSVS catalogue [25] are re-examined.

5. *K-Band Absolute Magnitudes And Distances*. We estimated the absolute K-band magnitudes and distances to the objects from the 2MASS [31] K magnitudes (assuming that K magnitude variation is negligible) using the following Period-Luminosity (PL) relations separately.

For Mira-type variables a revised PL relation [32] was applied:

$$M_K = -3.56 \times \log P + 1.14 \, (\sigma = 0.26 \, \mathrm{mag}) \tag{1}$$

For a SR variables a new PL relationship was applied [33]:

$$M_K = -1.34(\pm 0.06) \times \log P - 4.5(\pm 0.35) \tag{2}$$

which is based on K band luminosity analyse and revised Hipparcos parallaxes. For Irr variables to estimate the distances, $M_K = -6.5$ was adopted [34].

In Table 1 the data for the 54 FBS N-type AGB C stars are presented; the columns are: Column 1: running FBS and DFBS number according to catalogue [19] and according to papers [21,22], column 2: CSS (CSS, MLS, and SSS), or NSVS associations (if CSS is absent), column 3: variability type

Table 1

DATA FOR 54 FBS N-TYPE AGB CARBON STARS

FBS or DFBS Number	CSS and NSVS Association	Var. Type	Period days	$M(K)$ mag	D kpc	Z kpc	Notes
1	2	3	4	5	6	7	8
0042+484	NSVS 0045010+484104	SRA	300	-7.80	4.0	-0.9	
0043+474	NSVS 0046245+474135	Mira	344	-7.90	3.6	-0.9	
0110+397	CSS J0112 56.5+395944	SR	250	-7.70	7.5	-2.9	
0137+400	CSS J014020.6+401518	SR	329	-7.85	5.1	-1.8	1
0144+369	CSS J014736.3+371229	SR	140	-7.37	17.0	-7.0	
0155+384	CSS J015806.1+383818	Mira	300	-7.67	7.9	-3.0	
0158+095	CSS J020056.1+094535	Mira	400	-8.12	11.0	-8.3	
0210+464		Irr		-6.50	8.3	-1.8	
0324+389	CSS J032707.7+234847	SR	170	-7.40	7.5	-1.8	
0328+390	CSS J033133.6+391450	SR	276	-7.70	21.9	-5.2	
0337+386	CSS J034017.8+384538	SR	325	-7.85	8.3	-4.3	
0359+085	CSS J040143.3+084210	SR	398	-7.90	15.8	8.2	2
0502+088	CSS J050500.3+085607	Mira	340	-7.80	5.7	1.8	

Table 1 (The end)

1	2	3	4	5	6	7	8
0518+687	CSS J052400.2+685000	SR	380	-7.90	7.5	2.3	
0520+029	CSS J052302.3+030144	SR	270	-7.70	7.9	-2.4	
0645+375	CSS J064823.4+372856	SR	389	-7.90	9.5	2.5	
0656+351	CSS J070001.7+350555	SR	350	-7.90	7.5	2.2	2
0658+400	CSS J070148.9+395951	SR	375	-7.80	12.0	3.8	
0702+402	CSS J070607.8+401200	SR	320	-7.80	9.0	3.0	
0707+270	MLS J071047.9+265902	SR	383	-7.80	4.3	1.1	
0707+310	MLS J071048.3+305545	SR	184	-7.50	3.9	1.1	
0729+269	CSS J073232.8+264715	Mira	165	-6.75	10.0	3.4	2
0731+274	CSS J073423.9+271911	SR	325	-7.80	11.5	4.1	2
0800+368	CSS J080352.8+364443	SR	70	-6.80	13.2	6.5	
0826+185	CSS J082915.2+182307	SR	325	-7.80	9.0	4.4	
0826+109	CSS J082929.0+104624	SR	295	-6.90	10.0	4.4	
0846-071	CSS J084911.0-072144	SR	350	-7.00	15.8	5.9	3
0910+197	CSS J091331.9+193422	SR	254	-6.90	6.9	4.4	2
1008-66	CSS J101037.0-065113	SR	333	-7.80	18.2	11.3	3
1056+399	CSS J105923.9+394405	SR	198	-7.50	24.0	21.4	
1331+421	CSS J133319.4+415451	SR	142	-6.67	9.0	8.6	
1339-070	CSS J134226.8-071523	SR	290	-7.80	17.0	13.6	3
1416+640	CSS J141807.7+634906	SR	131	-7.30	22.9	17.7	
1502+359	CSS J150455.3+354757	SR	312	-7.80	30.2	26.2	
1515+666	CSS J151545.4+662604	SR	305	-7.70	7.9	5.5	
1516+151	CSS J151840.3+145903	SR	333	-7.80	11.0	8.8	
1524+046	CSS J152723.6+042827	SR	310	-7.80	15.1	11.0	2
1618-087	CSS J162136.3-085319	SR	365	-7.90	13.8	6.4	3
1705+402	CSS J170650.8+401234	Irr		-6.50	15.8	9.3	
1713+527	CSS J171447.6+524006	SR	205	-7.59	24.0	14.0	
1756+226		SR	143	-7.30	11.5	4.1	
1812+455	CSS J181329.4+453119	Mira	400	-8.12	9.0	3.8	
1918+869	NSVS 1900462+870340	SR	90	-7.00	7.2	3.2	
1934+545		SR	300	-7.80	15.8	4.3	
2107+109	CSS J210958.9+111101	SR	200	-7.50	20.0	8.1	
2157+400		SR	250	-7.70	11.5	-1.7	
2213+421		Mira	170?	?	?	?	4
2219+333	CSS J222113.8+333558	SR	202	-7.58	9.0	3.0	
2348+485		SR	172	-7.49	7.5	-1.6	
J020008.95+413737.4	CSS J020008.9+413747	SR	383	-7.90	20.0	-6.6	5
J032912.92+445330.0		SR	340	-7.89	8.7	-1.4	5
J064958.74+741610.1	NSVS 0649582+741611	Mira	356	-7.90	5.9	2.5	5
J172825.82+700829.6		SR	250	-7.70	21.9	11.7	5
J230835.19+403533.9	CSS J230835.1+403534	Mira	361	-7.90	12.9	-4.0	5

Notes to individual objects (1). For FBS 0137+440, the same parameters estimation are presented in paper [35], (2) - for this objects the same MLS associations is available also as CSS, (3)- for this objects same SSS associations is available also, as CSS, (4) - for FBS 2213+421 (V0381 Lac) the AAVSO database gives P = 170 day, (5) - see distance estimations in paper [21] also.

of object (Mira, SR, or Irr), column 4: pulsation period, column 5: absolute K-band magnitude estimation M_K, column 6: the distance D from the Sun, column 7: the heigh Z from the Galactic plane, and column 8: notes to individual object. The accuracy of the determination D and Z is estimated about 20 percent.

In Fig.1 and 2 the NSVS light curve and CSS light curve for FBS

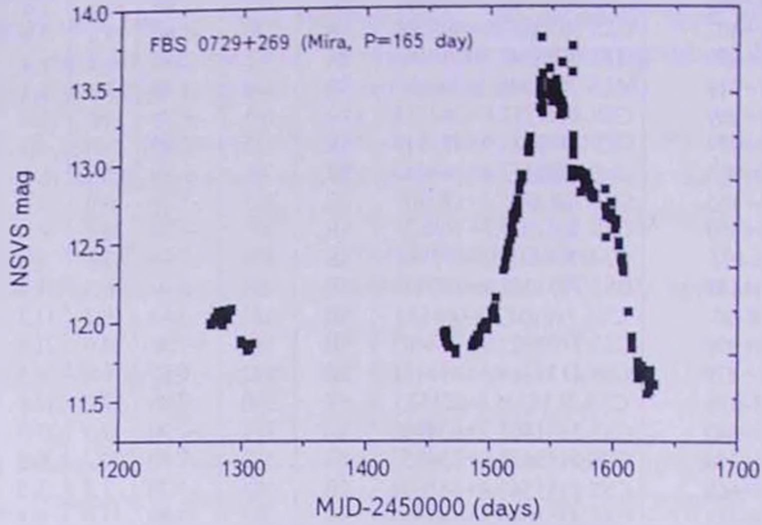

Fig.1. Phase dependence NSVS light curve for FBS 0729+269. X-axis presents the period in Julian Data and Y- axis presents the NSVS magnitude.

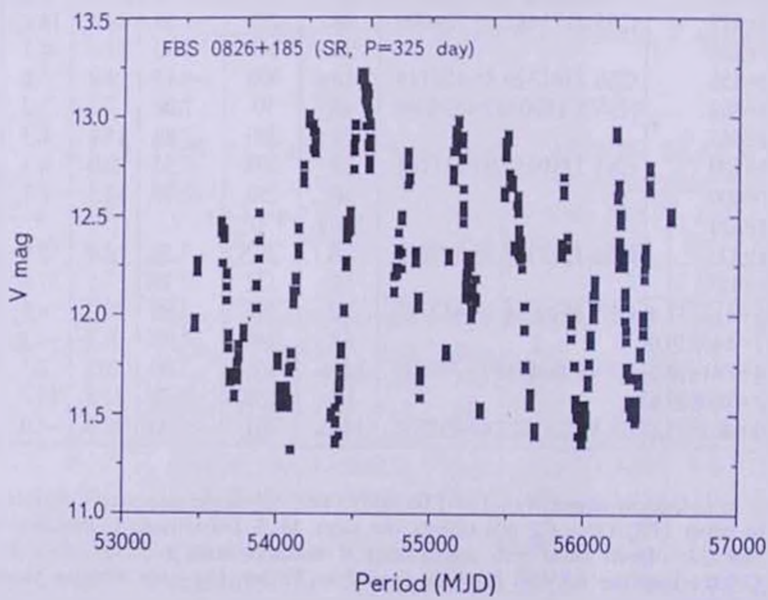

Fig.2. Phase dependenc CSS light curve for FBS 0826+185. X-axis presents the period in Julian Data and Y-axis presents CSS V band magnitude.

0729+269 and FBS 0826+185 respectively are presented, classified as a Mira and SR-type variables. Fig.3 presents the 2MASS [31] two-colour diagram for the 54 N-type stars discussed in this paper and 66 stars, showing early-type C stars characteristics [19]. A very red colour indices for FBS 2213+421 ($H - K = 2.408$ and $J - H = 3.011$) indicate that it is a cool/or more heavily extincted object (upper-right plot on Fig.3).

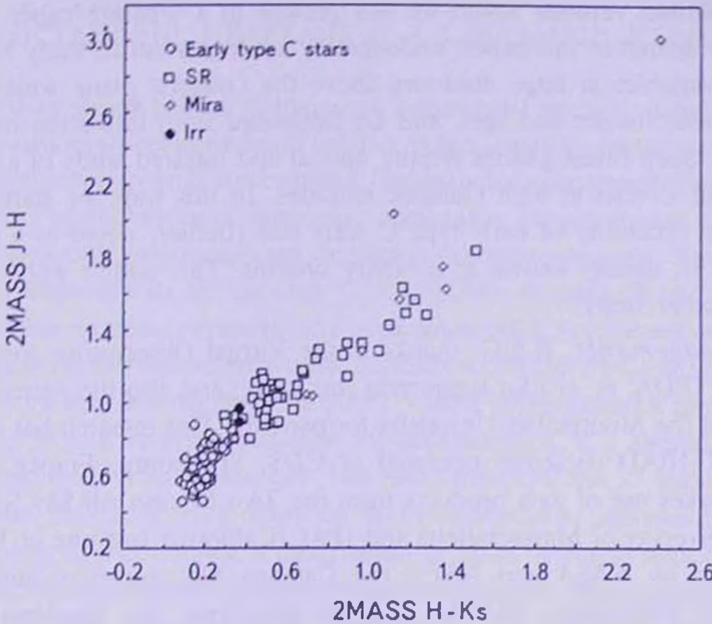

Fig.3. 2MASS near-infrared *JHKs* colour-colour plots for 54 N-type FBS C stars (Table 1) and 66 early-type C stars (open circles). SR variables are noted as open squares, Miras - as diamonds, and Irr-variables as dots.

6. *Discussion And Conclusion*. Variability study is one aspect of our programs aimed to investigate C stars detected on the FBS spectral plates. In this paper, we have examined optical variability for 54 N-type C stars using the two most prominent wide-area sky surveys, the Catalina Sky Survey and the Northern Sky Variability Survey, to clarify their variability nature. 9 objects are Mira-type variables, 43 are SR, and 2 Irr-type variables. The lowest ($Z = 0.9$ kpc) and highest values ($Z = 26.2$ kpc) from the Galactic plane are found for objects FBS 0042+484, FBS 0043+474, and FBS 1502+359 consequently. The maximum period estimated for SR variables among the targets, is $P = 398$ days (FBS 0359+085). The K band maximum absolute magnitude ($M_K = -8.12$) was estimated for two objects, FBS 0158+095 and FBS 1812+455, both having a period of 400 days. This value is in good agreement with the possible

[33], which corresponds to a bolometric luminosity of about $5000 \div 6000 L_{\odot}$, the expected luminosity for AGB stars. The lowest luminosity Mira found is FBS 0729+269 (M_K = -6.75) which is at 3.4 kpc distance from the Galactic plane. The faintest limit found in CSS V band is near 16 mag (FBS 0645+375 and FBS 1812+455). We do not found any Very Long-Period (VLP, $P > 500$ days) Mira-type variables among the targets analysed in this paper. Recent new NIR observations for FBS 2213+421 ($\Delta K > 1.6$ mag) show, that this object is a Large-Amplitude Variable which we will present in a separate paper.

Results presented in this paper, undoubtedly are important to study Miras, SR, and Irr variables at large distances above the Galactic plane which are objects of various masses and ages, and are important from formation history point of view. Such investigations require optical and infrared study of a large sample of faint C stars at high Galactic latitudes. In this way, we started to investigate the variability of early type C stars also (outlier, noted as a open circles in Fig.3), usually known as a binary systems. This outlier will be the subject of another study.

Acknowledgements. K.S.G. thanks to the Virtual Observatory communities (IVOA, IPDA, et. al.) for supporting this study, and also the Astronomy Department of the Montpellier University for partially. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This publication makes use of data products from the Two Micron All Sky Survey - 2MASS (University of Massachusetts and IPAC/California Institute of Technology, funded by NASA and NSF), the Catalina Sky Survey (California Institute of of Technology, NASA), and the data from the Northern Sky Variability Survey created jointly by the Los Alamos National Laboratory and University of Michigan. This study was possible thanks to open databases and tools developed in the frame of the International Astronomical Virtual Observatory.

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ИССЛЕДОВАНИЕ СЛАБЫХ ГАЛАКТИЧЕСКИХ УГЛЕРОДНЫХ ЗВЕЗД ИЗ ПЕРВОГО БЮРАКАНСКОГО СПЕКТРАЛЬНОГО ОБЗОРА НЕБА. ОПТИЧЕСКАЯ ПЕРЕМЕННОСТЬ. I. ЗВЕЗДЫ АВГ КЛАССА N. АБСОЛЮТНЫЕ ВЕЛИЧИНЫ В ПОЛОСЕ K, И РАССТОЯНИЯ

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В настоящей работе приводятся результаты исследований оптических переменностей сравнительно слабых углеродных С-звезд, выявленных на низкодисперсионных пластинках Первого Бюраканского Обзора неба на высоких галактических широтах, используя современные базы данных переменности, охватывающих большую поверхность неба. Кривые блеска, заимствованные из баз данных CSS и NSVS обзоров, были изучены для выяснения природы переменности этих объектов. В настоящей работе (первой в данной серии) приведены типы переменности для 54 С-звезд класса N на асимптотической ветви гигантов (АВГ). 9 звезд принадлежат к группе Миридов (Mira), 43 - к полуправильным SR-переменным, а 2 звезды - к группе неправильных Irr-переменных. Тип переменности для 27 звезд приводится впервые. Для всех этих объектов были определены абсолютные звездные величины K, расстояния, и расстояния от галактической плоскости. Целью данного исследования является лучшее понимание природы отобранных С-звезд на базе спектроскопии, данных 2MASS цветов и переменностей. Большинство программ, используемых в этом исследовании, были разработаны в рамках Астрономической Виртуальной Обсерватории.

Ключевые слова: *Звезды АВГ класса N: переменность: светимости в полосе K: расстояния*

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