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INVESTIGATION OF FAINT GALACTIC CARBON STARS FROM THE FIRST BYURAKAN SPECTRAL SKY SURVEY. II

K.S.GIGOYAN[1], A.M.MICKAELIAN[1], N.MAURON[2]

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Using recent astronomical databases, we investigate the characteristics of a list of new Galactic carbon (C) stars. These stars were discovered on the First Byurakan Spectral Sky Survey (FBS) plates and constitute the second part of our search for such objects. This second list of FBS C stars contains 44 objects. Slit spectra obtained by us with the BAO 2.6-m telescope confirm the carbon-rich nature of all of them. The list comprises 12 N-type carbon stars, and 32 CH-type stars. We consider spectral types, *B* and *R* magnitudes retrieved from the USNO-B1.0 catalog, and *JHK*, near-infrared photometry for stars extracted from the 2MASS point-source catalog. The *R* magnitudes of our objects are in the range 10 to 14. We derive distance estimates for all objects and find that most of the stars are located between approximately 3 and 20 kpc from the Sun. Their heights above or below the Galactic plane are in the range 1.5 to 13.0 kpc.

Key words: *stars: carbon*

1. ***Introduction.*** Stars showing a carbon-rich atmosphere are generally either cool giants evolving at the Asymptotic Giant Branch (AGB) or binary giants having carbon material gained from a companion. Carbon (C) stars are easily recognizable thanks to their pronounced molecular bands and consequently can be found in optical prism-objective surveys. In addition, thanks to their relatively high luminosity, C stars are valuable objects for investigating the kinematics and the stellar populations of our Galaxy and of nearby external systems (see for instance the review paper by Wallerstein and Knapp [1] and Groenewegen [2], as well as papers [3-8], devoted to C stars in external systems). C stars found in the Galactic halo are of specific interest and they can be detected up to large distances from the Sun and the Galactic center. The importance of investigations of these faint high-latitude C stars (FHLCs) are mentioned by the authors of paper [9], as well as by us in our first paper of this series [10].

Recently, 251 very faint FHLC stars were discovered by the authors of papers [11,12] by using the Sloan Digital Sky Survey (SDSS) optical data. These faint objects are either dwarf C stars located close to the Sun, or CH-type distant objects. The works of Mauron et al. [13,14] extend the search of N-type FHLC stars to rather astonishing distances, up to 130 kpc. Their objects are selected from the 2MASS infrared survey database, and the result

was the discovery of 50 new faint and distant N-type C stars in Galactic halo [13,14].

Many-sided investigations of various classes of C stars, such as the early R-type objects, the CH-type ones or the N-type stars are important. Their distances and their heights from the Galactic plane can help to know the origin of these objects. From this point of view, the C stars discovered on the First Byurakan Spectral Sky Survey (FBS) plates at high galactic latitudes undoubtedly represent a valuable material although that they are comparatively bright objects compared to the objects discovered in surveys mentioned above. Comprehensive data for the first part of the FBS detected C stars containing 35 objects are presented in Paper I of this series [10], where data about FBS survey and criteria of selection of R- and N-type C stars, as well as of M-type stars, were also described. In this paper, we present the second part of our studies on C stars found in the FBS plates.

2. *Second list of FBS C stars.* The FBS survey covers on the sky a total area of 17000 deg^2 segmented in 28 parallel zones (Markarian et al. [15]). In Table 1 we present the spectroscopically confirmed C stars of the second part of FBS with their photometric data. The sky area that we surveyed for this second part is nearly 10000 deg^2. A total of 44 C stars are presented in Table 1. Late M-type stars were also discovered on FBS plates as four separate lists, and preliminary spectral types, coordinates and finding charts were published in papers [16-19].

Table 1 present the following quantities. Column 1: running number; column 2-6: photometric data from the USNO-B1.0 [20] catalogue, i.e. its *B1*, *R1*, *B2* and *R2* magnitudes extracted from red and blue plates taken in the last 50 years (data available at the web site http://cdsweb.u-strasbg.fr/viz-bin/VizieR?-source = I/284); columns 7-9: 2MASS *J*, *H* and K_s near-infrared magnitudes (http://irsa.ipac.caltech.edu/cgi-bin/Gator/nph-dd); and column 10: corresponding references.

Table 1

THE USNO-B1.0 AND 2MASS PSC DATA FOR 44 FBS C STARS

№	FBS Number	*B1* mag.	*R1* mag.	*B2* mag.	*R2* mag.	*J* mag.	*H* mag.	K_s mag.	Ref.
1	2	3	4	5	6	7	8	9	10
36	0318+238	12.72	10.26	11.78	10.18	8.567	8.023	7.816	[19]
37	0502+088	15.99	13.30	16.51	13.26	8.741	7.181	6.036	[18]
38	0520+029	15.70	11.60	14.78	11.11	8.347	7.330	6.757	[18]
39	0707+270	19.08	12.07	15.87	12.66	8.222	6.663	5.448	[19]
40	0707+310	16.53	11.36	15.15	11.98	8.167	7.131	6.598	[19]
41	0729+269	15.17	11.35	14.46	11.23	9.886	8.852	8.155	[19]
42	0731+274	16.33	11.62	15.15	12.47	9.273	8.188	7.539	[19]
43	0826+185	15.56	10.99	14.86	12.78	8.748	7.709	7.067	[19]

Table 1 (the end)

1	2	3	4	5	6	7	8	9	10
44	0826+109	20.21	13.73	16.83	12.34	10.260	9.008	8.138	[18]
45	0900+034	14.32	11.31	13.81	12.09	10.005	9.316	9.131	[18]
46	0904+213	13.31	11.04	13.27	11.14	9.707	9.087	8.955	[19]
47	0916+029	13.14	10.78	13.16	10.88	9.267	8.652	8.471	[18]
48	1043+213	15.55	10.89	14.13	10.92	9.347	8.671	8.472	[19]
49	1043+253	15.51	12.45	14.45	12.28	10.657	9.913	9.722	[19]
50	1140+038	13.58	11.26	13.04	11.43	9.857	9.288	9.175	[18]
51	1145-000	14.86	12.18	14.73	12.37	10.911	10.240	10.006	[17]
52	1152-039	13.95	11.00	13.40	11.04	9.339	8.665	8.429	[16]
53	1225+077	14.79	12.40	15.14	12.91	11.541	10.990	10.852	[18]
54	1238-046	15.25	12.78	15.53	13.11	11.817	11.224	11.072	[16]
55	1305+015	14.70	12.42	14.42	12.33	10.621	9.994	9.814	[18]
56	1406+027	14.18	12.85	14.11	12.70	11.133	10.555	10.391	[18]
57	1418-031	14.91	12.11	14.33	12.41	10.505	9.767	9.505	[16]
58	1418+018	14.21	11.50	13.76	11.61	9.988	9.356	9.127	[18]
59	1440+263	14.78	11.76	14.34	12.02	9.959	9.255	9.061	[19]
60	1451+075	14.54	12.30	14.11	13.76	10.352	9.581	9.380	[18]
61	1516+151	15.44	11.31	14.06	11.59	8.973	7.845	7.342	[19]
62	1524+046	16.56	12.98	18.54	11.98	10.159	9.020	8.127	[18]
63	1547+046	14.44	12.79	13.39	11.35	10.539	9.967	9.786	[18]
64	1552-002	13.58	11.17	13.42	11.60	9.932	9.395	9.152	[17]
65	1553+119	14.23	12.63	14.89	13.12	11.292	10.724	10.557	[18]
66	1609-058	14.58	11.77	14.13	11.73	9.719	8.996	8.746	[16]
67	1612+262	15.26	13.13	15.45	12.92	11.698	11.069	10.900	[19]
68	1615-048	15.18	12.36	15.43	12.23	9.862	8.943	8.629	[16]
69	1619+160	15.18	12.53	14.73	12.33	9.946	9.170	8.852	[19]
70	1715+172	14.88	12.88	14.26	12.19	10.775	10.205	10.030	[19]
71	1728+216	13.77	10.86	13.03	10.87	9.089	8.371	8.137	[19]
72	1756+226	15.64	12.66	15.98	12.38	9.516	8.632	8.073	[19]
73	1825+272	14.40	12.59	13.94	12.45	11.149	10.693	10.498	[19]
74	2029+101	14.29	11.08	13.08	11.46	9.698	8.925	8.690	[18]
75	2100+123	15.77	12.72	14.62	12.07	9.899	9.053	8.723	[18]
76	2107+109	15.17	12.29	15.15	12.70	10.411	9.508	9.013	[18]
77	2158+197	14.47	12.04	14.33	12.15	10.916	10.432	10.290	[19]
78	2203+198	15.93	12.65	15.44	12.91	11.180	10.513	10.313	[19]
79	2217+100	15.13	12.51	14.83	12.42	11.054	10.054	10.251	[18]

Notes to Table 1: The objects FBS 0826+185, FBS 0826+109, and FBS 1524+046 were presented by us in lists [18,19] as N-type C star candidates. They were confirmed spectroscopically at the ESO NTT telescope and are included in the paper by Mauron et al. [14] where spectra covering the domain 6300-7900 Å are presented. These halo C stars are named 2MASS J082915.12+182307.2, J082929.03+104624.1, and J152723.59+042827.8 in [14]. On the contrary, observations did not confirm the carbon-rich nature for the objects FBS 0018+213, FBS 0300-030, and FBS 1058+081 presented as C stars in the lists [16,18,19]. It is interesting to note that information on proper motions and near-infrared *I*-band magnitude from the USNO-B1.0 catalogue are available for all objects from Table 1: all our objects do not show any detectable proper motion.

3. *Observations.* Spectroscopic observations for objects in Table 1 were carried out at the 2.6-m telescope of Byurakan Astrophysical Observatory (BAO, Armenia). The instrument was the SCORPIO spectrograph with a 600 g mm^{-1} grating. The detector was a Lick 3 2063 x 2058 CCD with $15 \times 15 \mu m$ pixels. The resulting dispersion is 1.7 Å per pixel [21], and the spectral resolution is 8 Å. The wavelength calibration and data reduction were performed with the ESO-MIDAS software.

The spectra allowed us to confirm the carbon-rich nature for objects of

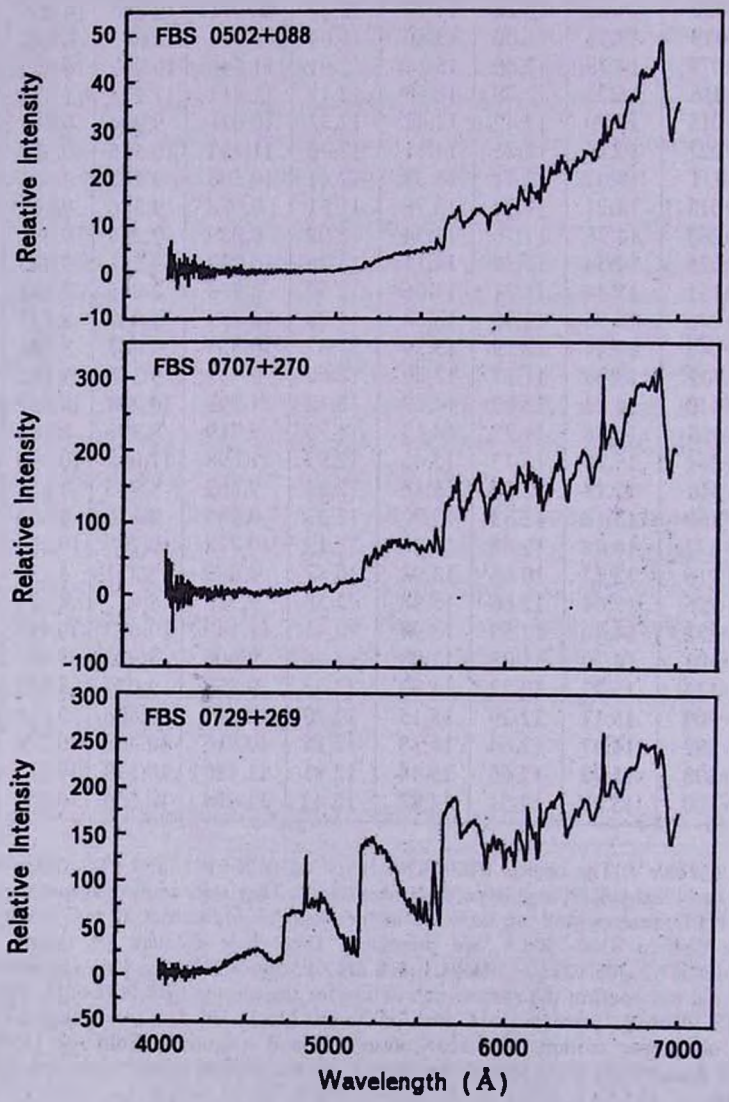

Fig.1.a. The 2.6-m BAO telescope spectra for N-type (Fig.1a) and CH-type (Fig.1b) FBS C stars from Table 1 in wavelength range 4000-7000 Å.

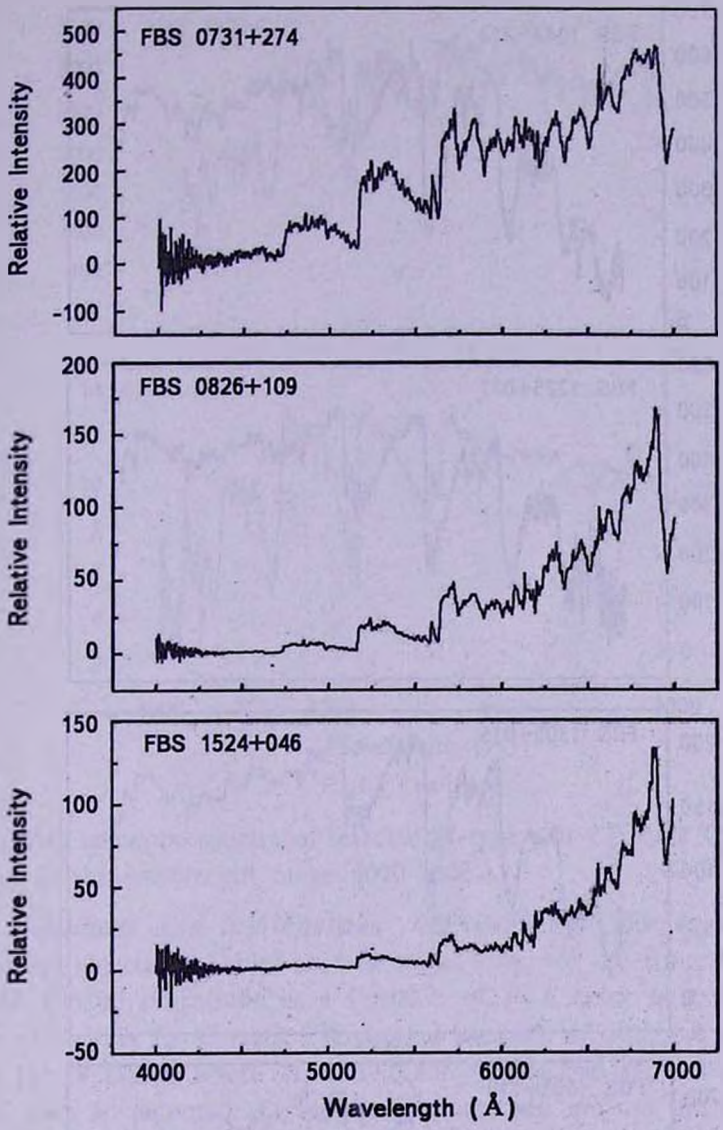

Fig.1.a. Continued.

Table 1, based on the presence in the wavelength range 4000-7000 Å of C_2 and CN molecule spectral strong features. Moreover, we detect the G-band of the CH molecule (at λ4300Å) in the spectra of 29 stars, allowing to distinguish them definitely as a subgroup of CH-type C stars. 12 objects are N-type C stars, out of which 5 objects show Balmer lines in emission, indicating that they belong to the group of Mira-like variables [22]. The remaining 3 objects are most probably CH-type stars too. Data from the journal of observations are presented in Table 2. Fig.1 (a, b) displays the

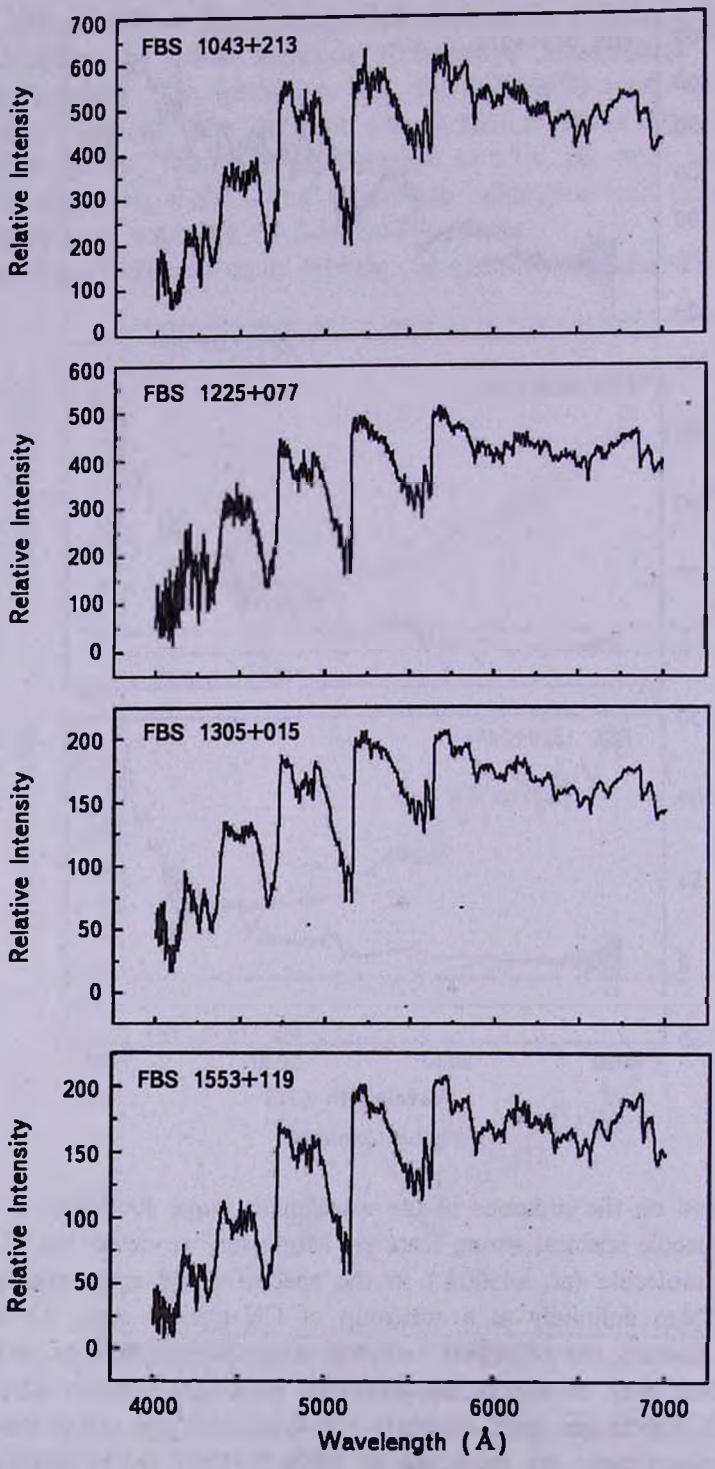

Fig.1.b. Continued.

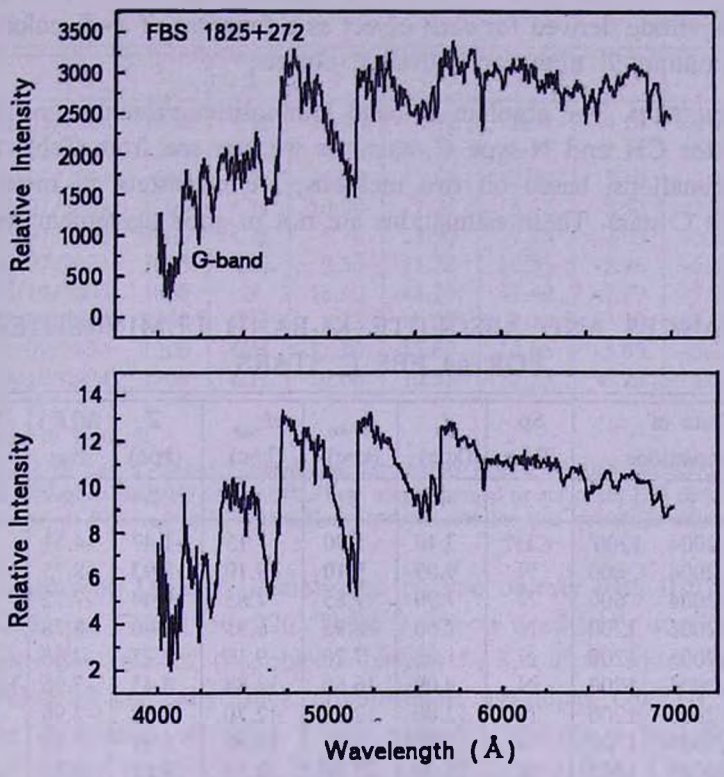

Fig.1.b. Continued.

2.6-m BAO telescope spectra of selected N-type and CH-type C stars from Table 1 in the wavelength range 4000-7000 Å.

4. *Distances and luminosities.* We estimate the distances and luminosities for objects of Table1 in two ways. First, we use the calibration of absolute K-band magnitude as a function of $J-K$ color index derived by Totten et al. [23] for C stars. The second estimate of distances is based on papers [13,14,23,24], where $M_R = -3^m.5$ for N-type and $M_R = -2^m.5$ for CH-type C stars are adopted. As for the R magnitude, we use the mean value of USNO-B1.0 *R1* and *R2*, presented in Table 1. The distance estimates, based on the two methods, the absolute K_s-band 2MASS magnitude, spectroscopically confirmed types, and other data are presented in Table 2. In this table, the columns have the following meaning: column 1: running number (as in Table 1); column 2: journal of observations (date and total exposure time); column 3: spectroscopically confirmed types of objects; column 4: the distance estimate based on R-magnitude (d_R); column 5: distance estimate based on 2MASS $J-K_s$ color index (d_{J-K_s}); column 6: final distance adopted by us, d_{adopt}, as a mean value of d_{J,K_s} and d_R; column 7: height (Z) above or below the Galactic plane; column 8: 2MASS K_s-band

absolute magnitude derived for each object as a function of $J-K_s$ color index [23], and column 9: note for individual objects.

5. *Discussion*. The absolute K_s-band luminosities presented in Table 2 are typical for CH and N-type C stars. As we can see from Table 2, the distance estimations, based on two methods, are consistent in most cases for CH-type C stars. These estimations are not in good agreement for only

Table 2

DISTANCES AND ABSOLUTE Ks-BAND LUMINOSITIES FOR 44 FBS C STARS

№	Data of Observations		Sp. Type	d_R (kpc)	$d_{(J-K_s)}$ (kpc)	d_{adopt} (kpc)	Z (kpc)	$M(K_s)$ mag.	Note
1	2		3	4	5	6	7	8	9
36	14/11/2004	1200s	CH?	3.40	2.90	3.15	-1.47	-4.51	
37	14/11/2004	600	N	9.09	9.10	9.10	-2.93	-8.75	
38	14/11/2004	600	N	7.90	7.85	7.85	-2.44	-7.72	
39	21/02/2005	1200	N	7.00	6.95	6.95	1.90	-8.78	Hα
40	21/02/2005	1200	N	11.00	7.20	9.10	2.71	-7.68	
41	22/02/2005	1800	N	9.09	16.60	12.84	4.45	-7.96	Hα , Hδ
42	22/02/2005	1200	N	12.80	12.60	12.70	4.52	-7.96	Hα
43	15/03/2005	1200	N	11.50	9.50	10.50	5.18	-7.88	
44	15/03/2005	1800	N	20.30	20.40	20.35	9.11	-8.42	Hα
45	15/03/2005	1800	CH	6.90	7.60	7.25	3.69	-5.25	
46	15/03/2005	1800	CH	5.01	4.90	4.95	3.11	-4.52	
47	15/03/2005	1800	CH	4.60	5.01	4.80	2.66	-4.80	
48	29/04/2003	1200	CH	4.80	5.50	5.15	4.49	-5.25	
49	29/04/2003	1800	CH	9.50	11.00	10.25	9.04	-5.60	
50	29/04/2003	1800	CH	5.70	4.36	5.03	4.41	-4.02	
51	29/04/2003	1800	CH	9.00	12.30	10.65	9.12	-5.43	
52	11/04/2003	1800	CH	5.10	5.70	5.40	4.46	-5.46	
53	11/04/2003	1800	CH	10.50	10.00	10.25	9.60	-4.10	
54	11/05/2000	1200	CH	12.30	12.80	12.55	10.63	-4.47	
55	11/04/2003	1200	CH	9.30	8.70	9.00	8.27	-4.87	
56	01/05/2003	1200	CH	11.00	9.50	10.25	8.80	-4.45	
57	11/05/2000	900	CH	9.00	12.00	10.50	8.34	-5.90	
58	11/05/2000	900	CH	6.60	7.25	6.92	5.78	-5.20	
59	11/06/2002	600	CH	7.60	8.00	7.80	7.07	-5.40	
60	01/05/2003	1200	CH	12.60	11.00	11.80	9.65	-5.77	
61	12/06/2002	600	N	9.50	9.00	9.25	7.45	-7.42	
62	15/03/2005	1800	N	15.80	19.50	17.65	12.80	-8.34	Hα
63	01/05/2003	1200	CH	8.00	7.25	7.62	5.08	-4.52	
64	01/05/2003	600	CH	5.80	5.90	5.85	3.60	-4.70	
65	04/05/2003	1200	CH	11.75	10.00	10.87	7.58	-4.40	
66	04/05/2003	1200	CH	7.25	8.00	7.62	3.96	-5.78	
67	04/05/2003	1800	CH	14.00	13.80	13.90	9.80	-4.81	
68	11/05/2000	1800	CH	9.10	11.50	10.30	5.25	-6.57	
69	11/05/2003	1200	CH?	9.50	6.75	8.12	5.25	-6.30	

Table 2 (the end)

1	2		3	4	5	6	7	8	9
70	11/05/2003	1800	CH	10.00	7.94	8.97	4.24	-4.47	
71	19/07/2002	240	CH?	4.80	5.75	5.27	2.38	-5.68	
72	25/07/2004	600	N	15.80	12.60	12.20	5.16	-7.40	
73	25/07/2004	1200	CH	10.00	7.25	8.62	2.52	-3.78	
74	23/07/2001	3000	CH	5.70	8.50	7.10	-2.05	-5.95	
75	23/07/2001	3600	CH	9.50	11.75	10.65	-3.96	-6.62	
76	26/10/2005	1800	N	16.60	18.20	17.40	-7.09	-7.30	
77	23/09/2004	2400	CH	8.33	6.03	7.18	-3.30	-3.60	
78	24/09/2004	1200	CH	11.50	12.60	12.05	-5.65	-5.22	
79	09/10/2004	1200	CH	10.00	10.50	10.25	-6.25	-4.85	

Note to Table 2:

The J, H and K_s 2MASS magnitudes for objects FBS 0502+088 (J050500.23+085607.8) and FBS 0707+270 (J071047.94+265902.7) are also presented in our paper [25] devoted to infrared properties of all FBS red stars, where the mass-loss rate for this objects is estimated.

three objects of Table 2, namely the N-type objects FBS 0707+310, FBS 0729+269, and FBS 1756+226. These 3 objects need to be studied in detail. It is also the case of the objects having $J-K_s > 2^m.0$, which are possibly surrounded by optically thick circumstellar envelopes [26,27]). Note also that for 26 objects of Table 1, the Galactic latitude is $|b| > 30°$, and the distance values presented in Table 2 are reddening free, i. e. we did not consider the interstellar extinction in R band and on $J-K_s$ color index.

Fig.2 displays $J-K_s$ *vs* $R-K_s$ (Fig.2a) and $J-H$ *vs* $H-K_s$ (Fig.2b) diagrams for objects of Table 1. As can be seen on both diagrams, the CH-type stars occupy a specific region, where in fact normal giants are located. The N-type C stars occupy another redder region, where AGB C stars are usually situated [13,14,23,24]. Two of the three doubtful objects (CH?) are located in the region of genuine CH stars, and should be considered as CH stars as well. The other one (FBS 1619+160), and three CH-type stars, namely FBS 1451+075, FBS 1615-048, and FBS 2100+123, are well separated from the main region in Fig.2a (as well as partly in Fig.2b), and might have an intermediate classification between CH and N types.

6. *Conclusion.* We have observed spectroscopically 44 candidate carbon stars from the second part of FBS with the BAO 2.6-m telescope and classified them into CH- either N-type C stars. Based on data retrieved from the recent astronomical catalogs, i.e. the USNO-B1.0 and the 2MASS point-source catalog, we have estimated the distances, 2MASS K_s-band absolute magnitudes, and heights from Galactic plane for these objects. 12 objects are N-type AGB C stars, and the remaining objects are CH-type giants. In spite of the fact that they are comparatively bright objects, they

surely deserve more detailed investigations in the future. High-dispersion spectra are needed to determine the radial velocity for both types of FBS

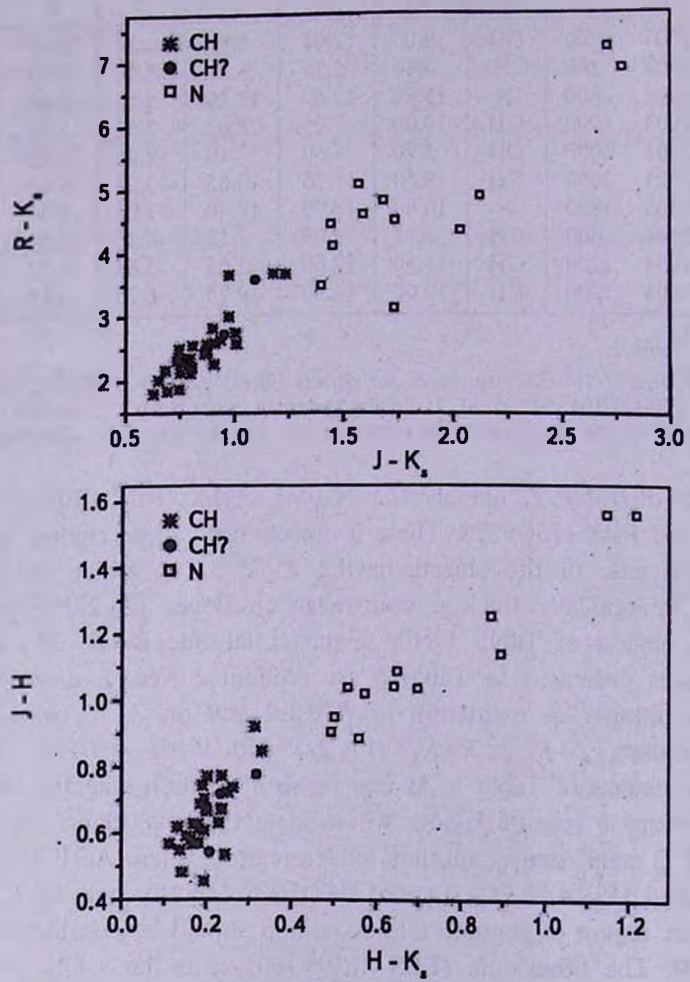

Fig.2.a, b. Color-color $J-K_s$ *vs* $R-K_s$ (Fig.2a) and $J-H$ *vs* $H-K_s$ (Fig.2b) diagrams for objects of Table 1. The *R*-magnitude is the mean value of *R1* and *R2*. The symbols indicate: asterisks - CH-stars, filled circles - possible CH stars, and open squares - N-type stars.

C stars. More detailed investigations are also needed to find the possible binary nature for CH-type giants, as well as the space distribution in Galaxy of both types of C stars at high galactic latitudes.

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[1] V.A.Ambartsumian Byurakan Astrophysical Observatory, Armenia, e-mail: kgigoyan@bao.sci.am, aregmick@apaven.am
[2] Groupe d'Astrophysique, CNRS & University de Montpellier, France, e-mail: mauron@kevin.graal.univ-montp2.fr

ИССЛЕДОВАНИЕ СЛАБЫХ ГАЛАКТИЧЕСКИХ УГЛЕРОДНЫХ ЗВЕЗД ИЗ ПЕРВОГО БЮРАКАНСКОГО СПЕКТРАЛЬНОГО ОБЗОРА НЕБА. II

К.С.ГИГОЯН[1], А.М.МИКАЕЛЯН[1], Н.МАУРОН[2]

Используя современные астрономические базы данных, изучены характеристики выборки новых галактических углеродных (С) звезд. Эти звезды были открыты на пластинках Первого Бюраканского спектрального обзора неба (FBS) и составляют вторую часть нашего поиска подобных объектов. Второй список С звезд FBS содержит 44 объекта. Щелевые спектры, полученные нами на 2.6-м телескопе БАО, подтверждают принадлежность всех этих звезд к группе углеродных. Список состоит из 12 углеродных звезд типа N и 32 звезд типа CH. В работе даны спектральные классы, B и R величины из каталога USNO-B1.0 и ближняя ИК-фотометрия JHK_s из каталога точечных источников 2MASS. Звездные величины R наших объектов находятся в интервале 10 и 14. Выведены приблизительные расстояния до всех объектов: большинство объектов расположено в интервале приблизительно 3 и 20 кпк от Солнца. Их высота от плоскости Галактики меняется между 1.5 и 13.0 кпк.

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