

A search for faint galactic carbon stars from the First Byurakan Spectral Sky Survey. I.*

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Abstract. We present and analyse in this paper the first results of a systematic search for Galactic carbon (C) stars using the First Byurakan Spectral Sky Survey (FBS). The present surveyed area extends over ~ 6140 deg² on the sky corresponding to $\sim 1/3$ of the complete FBS Survey. Accurate positions, spectral classifications, approximate B and R magnitudes, and finding charts are provided for 35 objects. Identification and spectral subclasses (R or N) of those stars, belonging to the magnitude range $10.5 \leq R \leq 16.4$, were determined by scrutinizing the Byurakan Schmidt telescope objective-prism plates. Subsequent slit-spectroscopic observations were obtained by us for 21 stars, confirming the carbon nature of them all. From this result, it is assumed that the remaining C star candidates are most likely carbon-rich stars as well. 18 of the listed objects at a Galactic latitude ($|b| > 30^\circ$) are faint enough ($R > 11.0$) to be considered as Faint High Latitude Carbon (FHLC) stars according to the definition of Totten & Irwin (1998). JHK magnitudes for 23 objects of our list are provided by the 2MASS database. Approximate distances are estimated from R and/or JHK data. Most of the stars are located between $d \simeq 7$ and $d \simeq 25$ kpc from the Sun while their distances z to the Galactic plane range from about 2 to 25 kpc. The most distant object of our sample is found at $d \simeq 45$ kpc and $z \simeq 40$ kpc. It is interesting to note that the rate of newly discovered FBS FHLC stars – one object per 200 deg² – is comparable to that achieved by other previous surveys. Consequently it is reasonable to expect that the full exploitation of the FBS plates might result in the identification of about 45 new FHLC stars.

Key words. stars: carbon – surveys – Galaxy: halo – Galaxy: stellar content

1. Introduction

Stars showing a carbon-rich atmosphere are generally either cool giants evolving on the asymptotic giant branch or binary giants having gained carbon material from a companion. Because they are easily recognizable thanks to their pronounced molecular bands and their relative high luminosity, carbon (C) stars are valuable objects to study the kinematics and stellar evolution of our Galaxy and of nearby external systems (see for instance the review

papers by Wallerstein & Knapp 1998; Groenewegen 1999). C stars found in the Galactic halo are of peculiar interest since they can be detected up to large distances, i.e. up to ≈ 100 kpc from the Sun and the Galactic center (Totten & Irwin 1998, hereafter TI98). Consequently, their kinematical properties provide information on the properties and mass of the halo (including dark matter) while their distribution may reveal and trace the tidal streams due to merging events in the history of the Galaxy (TI98, Ibata et al. 2000).

However, due to the scarcity of halo C stars (≈ 1 per 200 deg²), extensive systematic searches are mandatory to find this kind of object. Previous surveys have been carefully reviewed by TI98: they are mainly the Case low-dispersion Survey covering ≈ 1000 deg² of the North Galactic Cap (Sanduleak & Pesch 1988) and the University of Michigan Thin Prism Survey extending

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over 225 deg² of the South Galactic Cap (MacAlpine & Lewis 1978; Bothun et al. 1991), as well as the deep CCD survey for faint high-latitude carbon (FHLC) stars by Green et al. (1994) although this resulted in the discovery of only one carbon-rich star in the 52 deg² area searched. More recently, a major improvement in this domain was achieved by the APM Carbon Star Survey (TI98) which covers ≈ 7000 deg². In their Table 3, TI98 listed 48 high-latitude distant cool C stars of which 41 were either found or confirmed by the APM survey. TI98 performed slit spectroscopy of a sample of C star candidates selected through colour-magnitude diagrams obtained by scanning UKST, POSS1 or POSS2 plates. The selection criteria of the APM C stars, at $|b| \geq 30^\circ$, are $11 \leq R \leq 17$ and $B_J - R \geq 2.4$ (or ≥ 3.3 for POSS1 colours). The red colour cut-off favours the cool N-type C star detection as opposed to the bluer CH-type while the limits imposed in R can reveal objects as distant as 100 kpc. So far, a total of 71 FHLC ($|b| \geq 30^\circ$ and $R \geq 11$), not including dwarf C stars, are presently known.

In this context, we report here a search for faint Galactic C stars using the First Byurakan Spectral Sky Survey (henceforth FBS). This objective-prism survey was carried out by Markarian and associates (Markarian et al. 1989) over the 1965–1980 period using the Schmidt telescope of the Byurakan Astrophysical Observatory in Armenia. The FBS original goal was to identify objects with strong UV-excess in a region set by $|b| > 30^\circ$ and $\delta > -15^\circ$. Works related to the detection of white dwarfs, subdwarfs, QSO's and Seyfert galaxies have been reported elsewhere (Abrahamyan et al. 1990; Mickaelian et al. 1999). As a by-product, FBS plates can also successfully be used to survey late-type stars. Starting as early as 1986, this systematic search resulted in the discovery of more than 300 M-type and a number of C-type stars whose identifications have already be published in various brief reports (Abrahamyan & Gigoyan 1989, 1990a, 1990b; Abrahamyan et al. 1989; Gigoyan & Hambaryan 1989; Gigoyan et al. 1998).

We present in this paper a first updated comprehensive list of 35 newly identified C stars provided by the FBS survey over an area of about 6000 deg² covering both medium and high Galactic latitudes. Section 2 gives general information on the high-ranked C star candidates found in the FBS survey. For most of them, Sect. 3 presents spectra which helped us to confirm their carbon star nature, as well as visual and near-infrared photometric data coming mainly from the 2MASS database that have been used to derive the distances. Finally, the main results derived from this partial C star FBS survey are analysed and discussed in Sect. 4 that gives also predictions based on the near future, complete C star survey of the FBS plates.

2. FBS survey and carbon star identification

The FBS survey covers a total of 17 000 deg² segmented in 24 parallel zones (see Markarian et al. 1989). Photographic plates were obtained using the Byurakan 1-m Schmidt

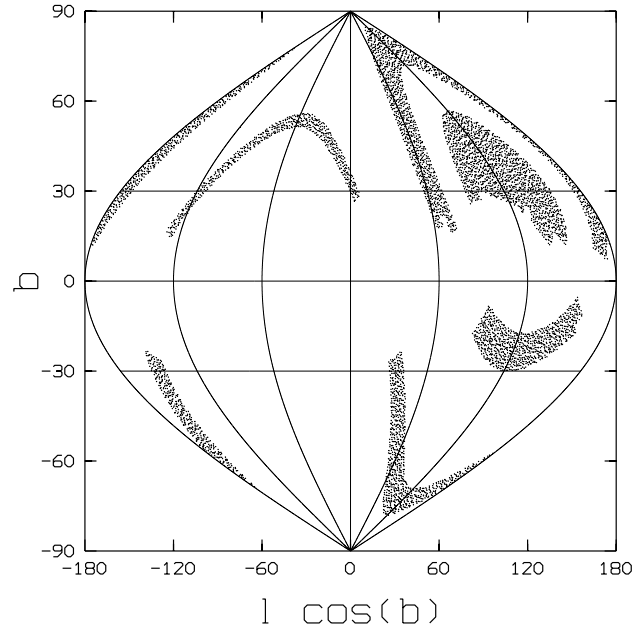


Fig. 1. Planisphere in $l \cos(b)$ versus b showing the the FBS sky survey regions searched for Galactic C stars (shaded zones)

telescope equipped with a 1.5° objective-prism giving a reciprocal dispersion of 1800 \AA mm^{-1} near $H\gamma$ throughout a useful field of $4^\circ \times 4^\circ$. During the observations, various Kodak emulsions were used (IIF, IIAF, IIAF and 103aF) providing a 3400–6900 \AA spectral range with a 70 \AA -wide gap at 5300 \AA . The resulting limiting magnitude is about 16 in the V band.

The large spectral range of the FBS plates is well suited to identify various types of objects, and especially cool M-type or C-type stars. Visual inspection with a magnification of $\times 15$ was used for selecting slitless spectra showing pronounced absorption bands. C stars can be identified through the presence of the Swan bands of the C_2 molecule at 4737, 5165 and 5636 \AA (N-stars). Several objects also showing the C_2 bandhead at 4382 \AA are probably carbon stars of R- or CH-type. Late M-type star spectra can easily be distinguished thanks to the TiO absorption bands. In practice, the limiting magnitude of the FBS survey for stars of late spectral classes is estimated to be ≈ 15.0 – 16.0 in the V -band (Abrahamyan & Gigoyan 1989). So far we have surveyed a total sky area of 6136 deg² which are distributed among 10 zones defined by the limits given in Table 1 and shown in Fig. 1. This area contains 4141 deg² at high Galactic latitude, 3054 deg² being located at $b > 30^\circ$ and 1087 deg² at $b < -30^\circ$.

Newly identified C stars by our partial survey of the FBS plates are listed in Table 2 where the columns give:

- *Column 1*: Running number. An asterisk indicates that the object meets the TI98 criteria to be thought as a FHLC star ($|b| > 30^\circ$ and $R > 11.0$).
- *Column 2*: FBS number.
- *Columns 3 and 4*: Right ascension and declination for equinox J2000 determined using POSS images in combination with the UNOSC-A2.0 catalog (Monet et al. 1998)

Table 1. Coordinates of the FBS area surveyed for C stars

Zone No.	Area deg ²	δ limits		α limits	
		°	°	h m	h m
1	1070	+37 < δ < +41	0 00 – 4 00	6 00 – 18 20	22 00 – 24 00
			0 00 – 4 00	6 00 – 19 00	22 00 – 24 00
			0 00 – 3 40	6 35 – 18 35	22 00 – 24 00
2	836	+41 < δ < +45	0 00 – 4 00	6 00 – 19 00	22 00 – 24 00
			0 00 – 3 40	6 35 – 18 35	22 00 – 24 00
3	879	+33 < δ < +37	0 00 – 4 00	6 00 – 19 00	22 00 – 24 00
			0 00 – 3 40	6 35 – 18 35	22 00 – 24 00
4	460	+61 < δ < +65	5 00 – 18 30	6 00 – 19 00	22 00 – 24 00
			5 00 – 18 30	6 00 – 19 00	22 00 – 24 00
5	309	+65 < δ < +69	5 00 – 18 30	6 00 – 19 00	22 00 – 24 00
			5 00 – 18 30	6 00 – 19 00	22 00 – 24 00
6	491	+69 < δ < +77	3 45 – 18 00	6 00 – 19 00	22 00 – 24 00
			3 45 – 18 00	6 00 – 19 00	22 00 – 24 00
7	128	+77 < δ < +80	3 40 – 18 30	6 00 – 19 00	22 00 – 24 00
			3 40 – 18 30	6 00 – 19 00	22 00 – 24 00
8	177	$\delta = +82.0$ $\delta = +86.0$ $\delta = +88.5$	5 45 – 18 35	6 00 – 19 00	22 00 – 24 00
			3 00 – 19 20	6 00 – 19 00	22 00 – 24 00
			0 00 – 24 00	6 00 – 19 00	22 00 – 24 00
9	658	-15 < δ < -11	0 00 – 5 20	6 00 – 19 00	22 00 – 24 00
			20 20 – 24 00	6 00 – 19 00	22 00 – 24 00
10	1128	-11 < δ < -07	0 00 – 5 20	6 00 – 19 00	22 00 – 24 00
			8 20 – 16 20	6 00 – 19 00	22 00 – 24 00
			20 20 – 24 00	6 00 – 19 00	22 00 – 24 00

and/or the APM catalog (Irwin 2000).

– *Column 5*: Galactic coordinates in degrees.

– *Column 6*: Spectral subclasses of the C stars (N or R) as determined by K.G. from the slitless objective-prism spectra; R-type stars are characterized by the presence of the C2 bandhead at 4382 Å in their spectra.

– *Column 7*: A “C” means that the carbon-rich nature of the C star candidate has been confirmed by subsequent spectroscopic observations.

– *Columns 8 and 9*: The R magnitude and $B - R$ index as given in the USNOC-A2.0 catalog.

– *Column 10*: Cross-identifications with IRAS sources; “P” refers to the PSC2 catalog and “F” to the FSC catalog.

– *Column 11*: Indication of the presence of H α , and often H β , in emission as shown by our medium-resolution spectra.

– *Column 12*: Notes as given at the end of the table.

Individual finding charts of size 5' \times 5' were extracted from the POSS Digital Sky Survey for all objects listed in Table 2, and are displayed in Fig. 2.

3. Subsequent observations and results

3.1. Slit-spectroscopy

Subsequent slit spectroscopy was carried out by us for 21 C star candidates in order to check their carbon-rich nature:

i) Two 300 line mm⁻¹ Grism spectra (3900–5300 Å

wavelength range) of the C star candidate FBS 0102-110 were obtained – as back-up observations – during the nights October 12 and 13 1996, at the 2.2-m ESO telescope equipped with EFOSC2 and a 2048 \times 2048 (15 μ m \times 15 μ m) pixels CCD camera as detector.

ii) Spectra in the range 7550–8000 Å were also obtained for 11 C star candidates during an observing run (Jan. 31 to Feb. 4 1997) with the Haute Provence 1.93-m telescope, equipped with the *Carelec* spectrograph and a 512 \times 512 (27 μ m \times 27 μ m) pixels Tektronix CCD camera as detector. A 1200 line mm⁻¹ grating was used, providing a resolution of about of 0.89 Å pixel⁻¹.

iii) Another observing run on June 26–29 1998 with the same telescope/instrument, but using a 300 line mm⁻¹ grating and a 2048 \times 1024 (13.5 μ m \times 13.5 μ m) pixels CCD detector (EEV 42-20), provided spectra with 1.75 Å pixel⁻¹ resolution for 11 objects.

All spectra were reduced and wavelength calibrated with the ESO-MIDAS reduction package. Spectrograms from the Haute Provence Observatory observations are presented in Figs. 3 and 4. FBS 0102-110 spectrograms are shown in the paper by Gigoyan et al. (1999).

Up to now, 22 out of the 35 C star candidates presented in this paper have had their carbon-rich star nature confirmed by subsequent slit-spectroscopy (FBS 1339-070 confirmation by TI98). In addition, FBS 0137+400 is also classified as a C-star from Low-Resolution IRAS Spectra (LRS) by Kwok et al. (1997). These results suggest that the C-star eye survey of the FBS plates by K.G. is very reliable, hence infers for the 13 remaining candidates (at least for the brightest ones with $R < 14.5$) a high probability of being carbon-rich stars as well. Note that 18 objects are FHLC, among which 10 received spectroscopic confirmation.

3.2. Radial velocities

Spectra over the 7500–8000 Å region allowed us to determine the radial velocities (RV) of 11 FBS stars. This was done by using spectra of three bright AGB carbon stars (U Hya, Y CVn, V Hya) taken during each observing night. These three objects are not actually RV standards since the photosphere of such AGB stars are known to pulsate with an amplitude of a few km s⁻¹. However, for simplicity, we will name them “standard” hereafter. Using three different standards allowed us to check our results and to increase the accuracy of our RV determinations. The adopted RVs of the standard stars were derived from the CO millimeter spectra of their circumstellar envelope, i.e. $v_{\text{helio}} = -23, +13,$ and -9 km s⁻¹ for U Hya, Y CVn, V Hya, respectively (from the v_{LSR} values which are given by Loup et al. 1993).

Each FBS C-star spectrum was cross-correlated with the spectrum of each standard star, in a manner similar to that described in detail by TI98. As a further check on the calculated RV, the FBS carbon stars were also cross-correlated with 7 RV “standards” from TI98. Both results

Table 2. List of proven and probable C stars provided by our partial survey of the FBS plates

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
No.	FBS No.	α (J)	δ (J)	l, b	sp		R	$B - R$	IRAS	em.lines	Notes
		h m s	° ' "	° °			mag	mag			
1*	0102-110	01 05 03.1	-10 49 14	135 -73	R	C	14.1	1.3			<i>a</i>
2	0137+400	01 40 20.6	+40 15 19	133 -22	N	(C)	10.5	7.0	P 01373+4000		<i>b, c</i>
3	0144+369	01 47 36.3	+37 12 30	135 -24	N	C	13.3	4.1			<i>d</i>
4	0259+444	03 02 27.1	+44 38 29	146 -12	R	C	12.8	1.8			
5	0324+389	03 27 31.4	+39 04 51	153 -14	N	C	11.8	4.2	F 03242+3854		
6	0328+390	03 31 33.6	+39 14 50	154 -14	N	C	13.9	3.5			
7	0337+386	03 40 18.1	+38 45 39	155 -13	N	C	11.6	4.5	F 03369+3835		
8	0518+687	05 24 00.2	+68 50 01	144 +18	N		11.4	3.7	F 05186+6847		
9	0644+616	06 49 11.1	+61 33 19	154 +23	R		11.5	2.1			
10	0645+375	06 48 23.3	+37 28 56	178 +15	N	C	12.2	3.5	P 06450+3732		<i>b, e</i>
11	0656+351	07 00 01.7	+35 05 56	182 +17	N	C	12.3	4.1	F 06567+3510		<i>d</i>
12	0702+402	07 06 07.8	+40 12 02	177 +20	N	C	12.4	3.5	F 07027+4016		
13	0800+368	08 03 52.8	+36 44 43	184 +29	R	C	12.7	2.5			
14	0846-071	08 49 11.0	-07 21 44	234 +22	R		13.5	3.0			
15*	0922+786	09 28 48.5	+78 25 46	134 +34	R	C	12.1	1.8			<i>a</i>
16*	0947-087	09 49 30.3	-08 59 37	246 +33	R		14.5	2.1			<i>f</i>
17*	1056+399	10 59 23.9	+39 44 06	177 +63	N	C	13.3	3.6		H α , H β	<i>g</i>
18*	1127+782	11 31 04.4	+77 59 47	128 +38	R	C	12.0	2.1			<i>a</i>
19*	1331+421	13 33 19.4	+41 54 51	096 +73	N	C	11.6	2.9		H α , H β	
20*	1339-070	13 42 26.8	-07 15 23	323 +54	N	C	13.1	2.8			<i>h</i>
21*	1416+640	14 18 07.7	+63 49 07	108 +51	N	C	12.3	3.1		H α , H β	
22*	1431-079	14 34 32.6	-08 08 37	342 +47	R		12.7	2.1			
23*	1434-080	14 37 25.9	-08 16 41	343 +46	R		14.3	1.3			
24*	1435-092	14 37 46.4	-09 26 60	342 +45	R		13.7	1.6			
25*	1502+359	15 04 55.3	+35 47 58	058 +60	N	C	16.4	5.0		H α	<i>i</i>
26*	1515+666	15 15 45.4	+66 26 04	103 +45	N	C	11.6	4.0	P 15151+6637	H α	<i>b</i>
27	1618-087	16 21 36.3	-08 53 18	005 +28	N		12.1	3.7			
28*	1713+527	17 14 47.5	+52 40 07	080 +36	N	C	12.6	3.2		H α , H β	
29	1919+869	19 01 03.7	+87 03 45	120 +27	N	C	11.6	2.2	F 19191+8658		
30	1934+545	19 35 18.8	+54 39 53	087 +16	N	C	13.7	5.7		H α , H β	
31*	2123-104	21 26 06.2	-10 13 46	042 -39	N		12.9	2.1			
32*	2143-081	21 46 38.0	-07 53 11	047 -43	R		14.8	0.9			<i>f</i>
33*	2144-089	21 46 40.6	-08 41 05	048 -42	R		14.5	1.7			<i>f</i>
34*	2207-095	22 09 57.5	-09 16 06	050 -48	N		12.7	2.1			
35	2219+333	22 21 38.6	+33 35 59	090 -20	N	C	13.2	3.7	P 22193+3320		<i>b</i>

Notes in Col. (12):

-*a*: The spectrum of this C-star displays strong CH features according to Gigoyan et al. (1999, 2000).

-*b*: This PSC object also belongs to the IRAS FSC catalog.

-*c*: Carbon star candidate identified by Abrahamyan & Gigoyan (1989); also classified C star from Low-Resolution IRAS Spectra (LRS) by Kwok et al. (1997).

-*d*: FBS 0144+369 and FBS 0656+351 are erroneously classified as galaxies in the Automatic Plate Scanner (APS) database (<http://aps.umn.edu>).

-*e*: This object is neither in the USNOC-A2.0 catalog nor in the APM catalog; B and R magnitudes have been estimated from image diameter measurements on POSS prints using the method by King & Raff (1977).

-*f*: The carbon-rich star nature of this object is unsure due to its relative faintness ($R \sim 14.5$) on FBS plates; further slit-spectroscopy confirmation is mandatory.

-*g*: Carbon star candidate identified by Abrahamyan & Gigoyan (1989); slit-spectroscopy confirmation is given in this paper.

-*h*: Carbon star candidate identified simultaneously by TI98 and Gigoyan et al. (1998); slit-spectroscopy confirmation by TI98.

-*i*: This object is not listed by the USNOC-A2.0 catalog; the APM catalog gives $R = 16.4$ only, while the magnitude determinations using POSS images are $R \approx 16.0$ and $B - R > 5$.

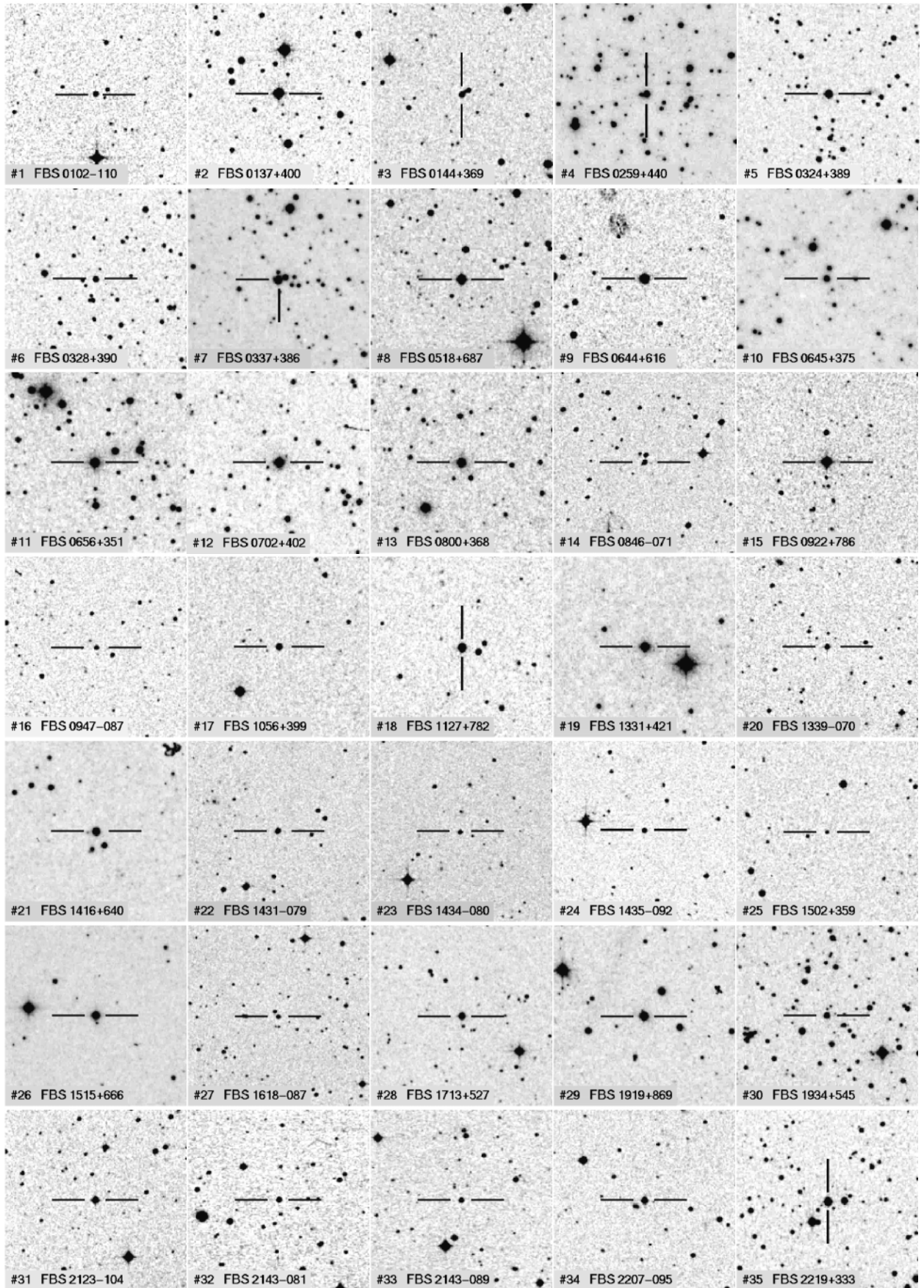


Fig. 2. Finding charts. Each image shows a 5×5 arcmin² region with north at the top and east to the left

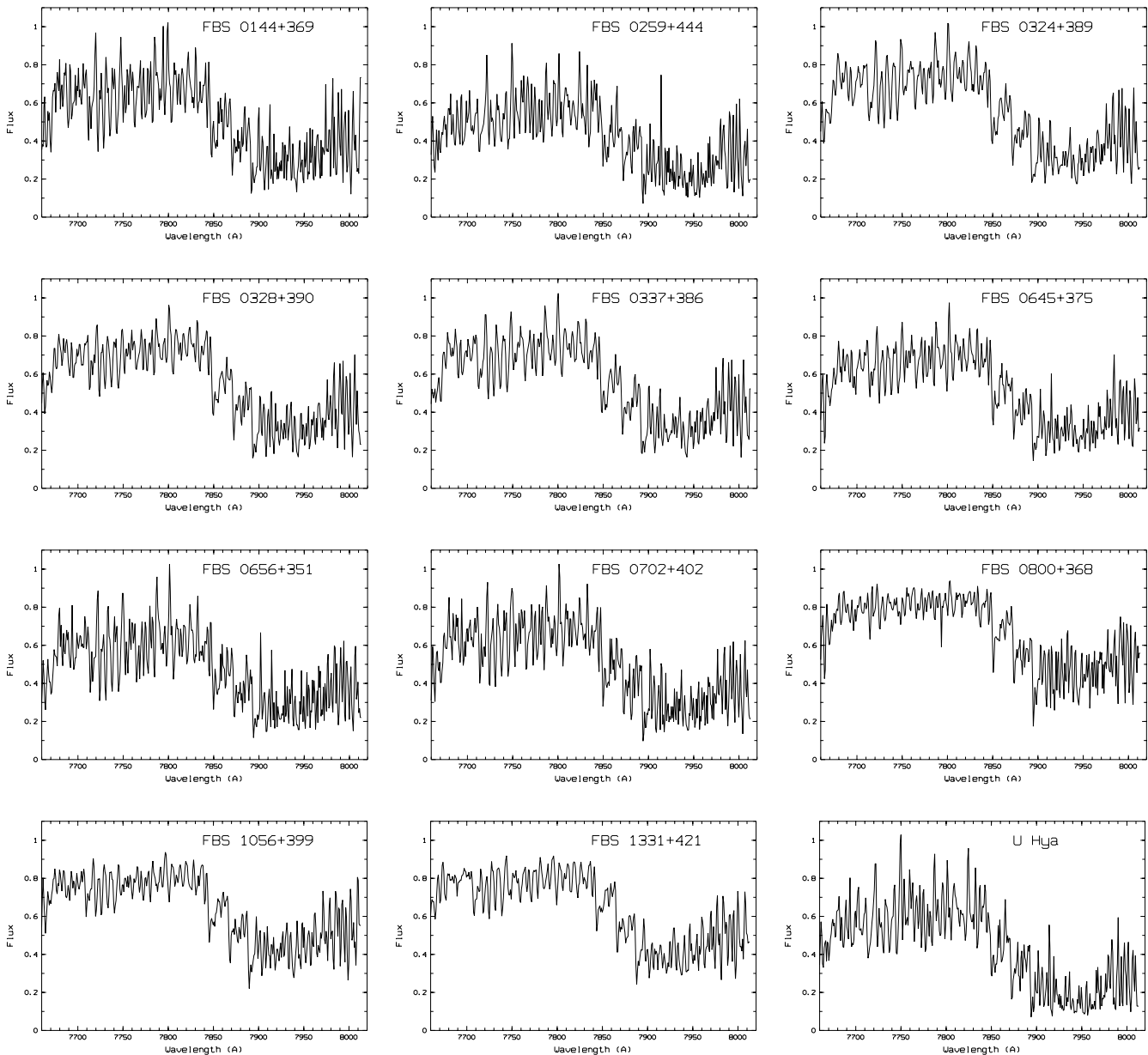


Fig. 3. High-resolution spectrograms for 11 Galactic C stars. The spectrum of U Hya used as radial velocity “standard” is displayed for comparison

were found in very good agreement (within $\sim 3 \text{ km s}^{-1}$). It is important to note that FBS1056+399 shows an anomalous cross correlation peak which was not well fitted by a Gaussian – the best possible fit was applied. The value given in Table 3 results from that fit.

3.3. Near-infrared photometry

Our main source for *JHK* magnitudes is the 2MASS Survey in its Second Incremental Release, which provided *JHK* data for 23 stars. These are listed in Table 3.

Near-infrared photometric observations were also kindly performed for us by Dr. Noguchi at the 1.26-m telescope of Beijing Astrophysical Observatory

(Hinglog, China) using the infrared photometer of Nagoya University (Japan). *JHK* data for 9 stars, presented in Table 4, were obtained during the period October 7–10, 1992. For a complete description of the photometer and the photometric system used, see Noguchi & Akiba (1986).

Since all the stars observed by Dr. Noguchi have also 2MASS photometry, we also give in Table 4 the differences between the two sets of data. It is plausible that part of the variations ($\approx \pm 0.1 \text{ mag}$) may be due either to experimental errors and bandpass differences, or slight variability of the objects. However, evidence for a significant variability is noticeable for C stars FBS 0137+400, FBS 1056+399, and FBS 2219+33; this is consistent with their N-type as set by our spectral classification.

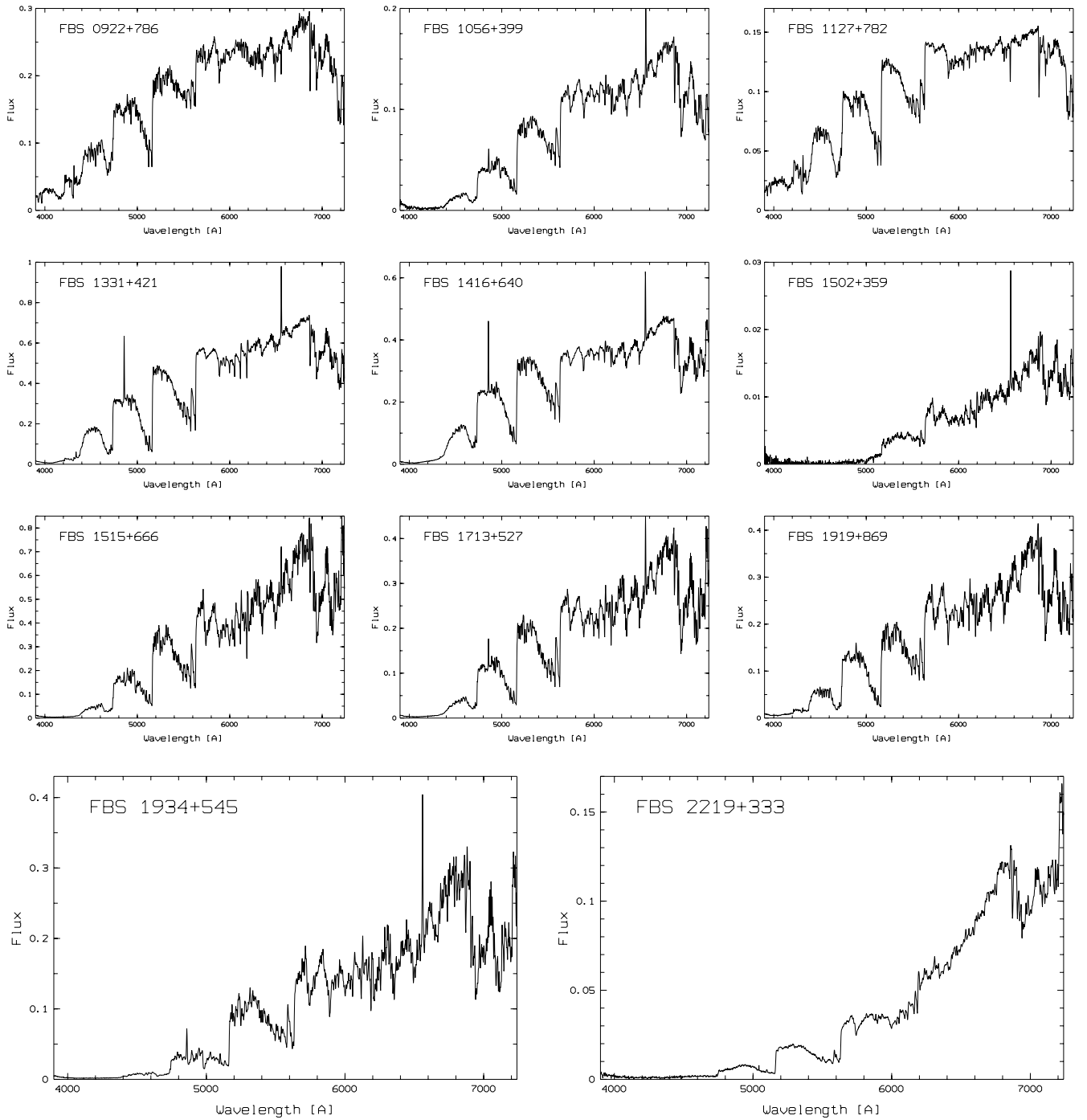


Fig. 4. Medium-resolution spectrograms for 11 Galactic C stars

A $J-H$ vs. $H-K$ diagram for the FBS objects is presented in Fig. 5 and compared to the colours of others known FHLC. According to the 2MASS Explanatory Supplement, the 2MASS photometric system is almost identical to that of Bessel & Brett (1988, hereafter BB88). Therefore, we have plotted these JHK diagrams using the BB88 system. Figure 5a shows a $J-H$, $H-K$ diagram for 70 previously known FHLC (no carbon dwarfs). The data come mainly from Table 3 of Totten et al. (2000, hereafter TIW) and in some case from Table 1 of TI98. The

SAAO and CIT/CTIO colour indices that have been published by TIW and TI98, respectively, were transformed into the BB88 system using the following relations (given in BB88):

$$(J-H)_{\text{BB88}} = +0.016 + (J-H)_{\text{SAAO}}$$

$$(H-K)_{\text{BB88}} = -0.021 + (H-K)_{\text{SAAO}}$$

$$(J-H)_{\text{BB88}} = +0.002 + 1.098(J-H)_{\text{CIT/CTIO}}$$

$$(H-K)_{\text{BB88}} = -0.00 + 1.03(H-K)_{\text{CIT/CTIO}}.$$

Table 3. *JHK* photometry, distance estimates and radial velocities for the proven and probable FBS C stars

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
No.	FBS No.		<i>J</i>	<i>H</i>	<i>K</i>	d_R	d_{JHK}	$d_{\text{adop.}}$	z	v_r
			mag	mag	mag	kpc	kpc	kpc	kpc	km s ⁻¹
1*	0102-110	C	12.56	12.05	11.90	20	14	16	-15	
2	0137+400	(C)	9.08	7.26	5.74	6	8	7	-2.5	
3	0144+369	C	10.51	9.42	8.86	21	22	22	-9	-113
4	0259+444	C	9.96	9.04	8.68	9	13	11	-2.5	-40
5	0324+389	C	8.66	7.56	7.03	9	9	9	-2.0	-52
6	0328+390	C				25		25	-6	-54
7	0337+386	C	8.63	7.46	6.80	8	9	9	-2.0	-79
8	0518+687					8		8	+2.5	
9	0644+616					5		5	+2.0	
10	0645+375	C	9.66	8.18	7.02	12	14	13	+3.5	-5
11	0656+351	C	8.48	7.35	6.63	13	9	11	+3.0	-21
12	0702+402	C	8.69	7.61	7.09	14	9	11	+4	-16
13	0800+368	C	9.98	9.09	8.80	10	12	11	+5	+14
14	0846-071		10.51	9.50	9.06	15	20	17	+6	
15*	0922+786	C	9.70	9.10	8.89	8	6	7	+4	
16*	0947-087		12.58	11.95	11.74	24	23	23	+12	
17*	1056+399	C	11.08	10.08	9.44	22	28	25	+22	-166
18*	1127+782	C	10.93	10.37	10.30	8	6	7	+4	
19*	1331+421	C	9.88	9.00	8.66	10	12	11	+11	-211
20*	1339-070	C				20		20	+16	
21*	1416+640	C	10.75	9.94	9.57	14	17	16	+12	
22*	1431-079					10		10	+7	
23*	1434-080					21		21	+15	
24*	1435-092					15		15	+11	
25*	1502+359	C	12.00	10.68	9.68	94	45	45	+40	
26*	1515+666	C				10		10	+7	
27	1618-087					9		9	+4	
28*	1713+527	C	10.71	9.84	9.32	16	21	18	+5	
29	1919+869	C				9		9	+4	
30	1934+545	C				24		24	+7	
31*	2123-104					18		18	-11	
32*	2143-081		14.02	13.49	13.41	27	23	25	-17	
33*	2144-089		12.50	11.81	11.68	24	21	22	-15	
34*	2207-095		10.56	9.81	9.59	17	12	15	-11	
35	2219+333	C	10.01	8.53	7.24	20	16	18	-6	

Notes to Table 3:

- *Column 1*: Running number. An asterisk indicates that the object is a FHLC star.
- *Column 2*: FBS number.
- *Column 3*: A “C” means that the carbon-rich nature of the C star candidate has been confirmed (see Table 2).
- *Columns 4, 5 and 6*: *J*, *H* and *K* magnitudes, respectively, from the 2MASS survey.
- *Column 7*: Heliocentric distance estimate from the USNOC-A2.0 catalog *R* magnitude (see Table 2).
- *Column 8*: Heliocentric distance estimate from *JHK* photometry.
- *Column 9*: Adopted distance estimate.
- *Column 10*: Distance to the Galactic plane.
- *Column 11*: Heliocentric radial velocity estimate (≈ 5 km s⁻¹ accuracy).
- Note on the distance of object #25 (FBS 1502+359): the colors of this star are very red, especially $B-R > 5$ (Table 2), suggesting circumstellar dust absorption; this probably accounts for the large discrepancy in distance estimates (see discussion).

Table 4. *JHK* photometry by Dr. Noguchi and magnitude differences with 2MASS photometry, where $\Delta mag = mag(\text{Noguchi}) - mag(2\text{MASS})$

FBS	<i>J</i>	<i>H</i>	<i>K</i>	ΔJ	ΔH	ΔK
0137+400	8.03	6.33	5.08	-1.05	-0.93	-0.66
0324+389	8.67	7.70	7.15	+0.01	+0.14	+0.12
0337+386	8.48	7.53	6.81	-0.15	+0.07	+0.01
0645+375	9.94	8.25	7.07	+0.28	+0.07	+0.05
0656+351	8.41	7.23	6.50	-0.07	-0.12	-0.13
0702+402	8.56	7.48	6.95	-0.13	-0.13	-0.14
0800+368	9.85	9.10	8.80	-0.13	+0.01	+0.00
1056+399	10.60	9.65	9.17	-0.48	-0.43	-0.27
2219+333	9.67	7.92	6.92	-0.34	-0.61	-0.32

Figure 5b displays a *J-H*, *H-K* diagram for the 23 FBS carbon stars with 2MASS photometry. One can note that the general pattern of the FBS colour indice plot is similar to that of Fig. 5a. However, these seem to be slightly shifted towards greater *H-K* and smaller *J-H* indices which could be explained by a systematic difference in *H* magnitudes between the 2MASS and the BB88 photometric systems. Figure 5b also suggests that the C star candidates FBS 2207-095 (lower left open circle) and FBS 0846-071 (upper right filled circle) might be of CH- and N-type, respectively.

3.4. Distance determinations

Two methods were adopted to derive approximate distances of the FBS stars. The first used the *R* magnitude provided for each star by the USNOC-A2.0, (see Table 2) which is probably known with an accuracy of ~ 0.4 mag only. According to TI98, we assumed for N-type stars $M_R = -3.5$, and for the others (presumably CH-type) $M_R = -2.5$. Because several stars lay at $|b| < 30^\circ$, the Galactic absorption in the *R*-band was taken into account and estimated from the Schlegel et al. (1998) extinction maps. For our sample A_R was found to reach up to 0.77 mag (for FBS 1618-087 at $b = +28^\circ$). The second method used the 2MASS photometry and the M_K vs. *J-K* relation set up for C stars, in the SAAO system, by TIW. This is not a real problem since the Bessel & Brett (1988) system used in the 2MASS catalog is virtually identical to the SAAO one. Differences in the region of a few hundredths of magnitude may be ignored since the typical dispersion in the M_K vs. *J-K* relation is about ± 0.5 mag in M_K . Distance estimates d_R and d_{JHK} resulting from the two methods are listed in Table 3.

It is noteworthy that the distance estimates that have been derived from *R* and *JHK* photometry independently are generally in rather good agreement. Consequently, we adopted for each star an average heliocentric distance,

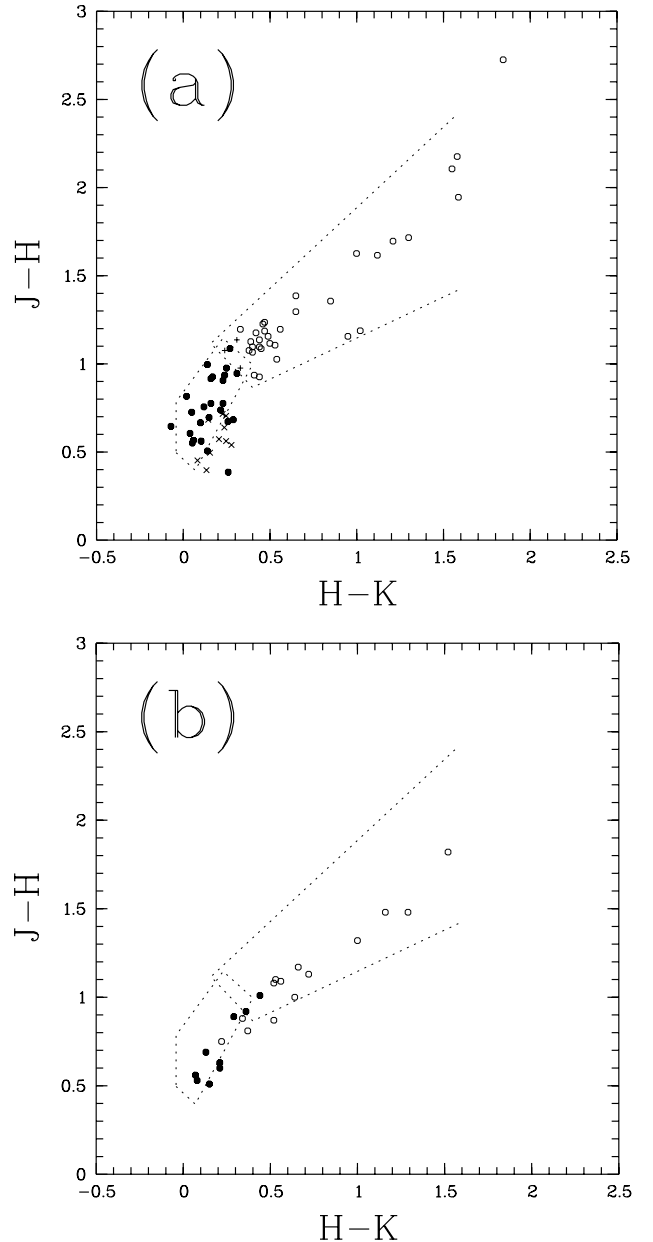


Fig. 5. *J-H*, *H-K* diagrams. **a)** Plot for 70 previously known FHLC stars from the lists of TI98 and TIW: open circles (N-type), filled circles (CH-type), plus signs (either N- or CH-type), crosses “x” (unknown C-type). The boundaries of the loci of CH- and N-type stars are those defined by TIW. Note that most of the unknown C-type stars likely belong to the CH-subclass; **b)** plot for the 23 FBS C stars with available 2MASS *JHK* photometry: open circles (N-type), filled circles (CH-type)

except FBS 1502+359 for which d_{JHK} was chosen (see the discussion below). Estimated distances to the Galactic plane z were also determined. Due to the uncertainties affecting *R*, M_R and M_K , errors on distances are probably of the order of $\pm 25\%$ at least. Estimated distances d_{adopted} and z are listed in Table 3.

4. Discussion

Our first list of Galactic C stars contains 35 objects of which 17 are located at $|b| < 30^\circ$: 13 belong to the N-subclass and 4 from the CH-subclass. Table 3 shows that the heliocentric distances of these 17 stars range between ~ 7 and 25 kpc and their distances to the Galactic plane from 2 to 9 kpc. Most of these stars should belong to the halo population, since the N-type C stars of the Galactic disk have a scale height of about 200–300 pc (Claussen et al. 1987; Groenewegen et al. 1992). Although interesting in itself, this sample of 17 C stars is far from being statistically complete due to large interstellar absorption in the visible at such galactic latitudes. So, it is not adequate to compare this subsample to any other ones from previous surveys.

However, the comparison with the APM survey is possible for the 18 C stars located at $|b| > 30^\circ$. The heliocentric distances of our FHLCs generally range between ≈ 10 and ≈ 25 kpc, with $|z|$ between ≈ 4 and ≈ 22 kpc (except for FBS 1502+359 discussed below). These distances are smaller than the distances of a number of FHLC found by TI98 and TIW which are located from about 20 to 100 kpc. This is due to the fact that the APM objects are significantly fainter than ours: about half of the APM C stars have $R \geq 14$, whereas only 6 over 35 from our list have $R \geq 14$.

Our newly discovered and spectroscopically confirmed FHLC star, FBS 1502+359, is the faintest of our sample ($R \simeq 16.4$), hence relatively distant ($d \simeq 45$ kpc and $z \simeq +40$ kpc). Both its medium-resolution spectrum and its $B-R$ colour index (>5) suggests that this object is surrounded by a dusty envelope. Consequently, we adopted the distance determined from JHK photometry, rather than the much larger one based on its R magnitude. The discovery of FBS 1502+359 lead us to think that a careful survey of the remaining FBS plates might reveal other faint interesting objects of this kind.

Our partial FBS C star survey resulted in the identification of 18 FHLC stars in an area of about 4100 deg² at $|b| > 30^\circ$, two objects (FBS 1056+399 and FBS 1339-070) also belonging to the TI98 list. Consequently, the frequency of FBS FHLC stars is about 1 object per 200 deg² which is comparable to the discovery rate of previous FHLC star surveys: for instance Green et al. (1994) found one FHLC star in a 52 deg² area and the APM survey brought 33 new faint FHLC stars over an area of 6500 deg².

According to the TI98 census, the total number of FHLC stars ($|b| > 30^\circ$, $R > 11$) known at that time was 71. With 16 newly discovered objects, the present FBS C-star survey – of a sky area intensively searched for this kind of object – increases by more than 20% the number of FHLC stars known. Since only one third of the total area covered by the FBS plates at $|b| > 30^\circ$ has been searched for C stars so far, one can expect that the FBS survey will provide about 30 more FHLC stars.

5. Conclusions

Faint high latitude carbon stars ($|b| > 30^\circ$, $R > 11$) are sparse, and only 71 objects of this kind were known (see TI98). Using the FBS sky survey we have searched for C stars. Up to now, objective-prism plates were eye scrutinized covering an area of ~ 6100 deg² of which 4100 deg² are located at high Galactic latitudes ($|b| > 30^\circ$). A total of 35 C star candidates were found, the carbon-rich star nature being spectroscopically confirmed for 23 of them. Among these 35 objects, 18 are FHLC stars (10 with subsequent slit-spectroscopy) and have heliocentric distances d ranging from about 5 to 25 kpc, except for our present most distant object which is located at $d \simeq 45$ kpc. It is expected that our survey, currently in progress, of the complete set of FBS plates, might provide another 30 FHLC stars.

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