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Some studies on First Byurakan Survey late-type stars

K. S. Gigoyan *[1]

[1]NAS RA V. Ambartsumian Byurakan Astrophysical Observatory (BAO), Byurakan 0213, Aragatzotn province, Armenia

Abstract

Markarian survey (or the First Byurakan Survey, FBS), was the first systematic survey of the extragalactic sky. This objective-prism survey was carried out in 1965-1980 by B. E. Markarian and his colleagues using the 1 m Schmidt telescope of the Byurakan Astrophysical Observatory and resulted in discovery of 1517 UV-excess (Markarian) galaxies. FBS low-resolution spectral plates have been used long period to search and study faint late-type stars (LTSs, M-type and C(carbon) stars) at high galactic latitudes. I will review in this paper the results obtained for late-LTSs using FBS spectral plates. At present the survey is digitized and DFBS database is available. This paper reports also recent new discovered C and M-type stars, and a huge amount of the LTSs candidates selected in the DFBS data base. This paper informed also detecting some amount of the new dwarf carbon (dC) star candidates.

Keywords: *Carbon stars: M stars: surveys: catalogues: data bases*

1. Introduction

Markarian survey (or First Byurakan Survey, FBS) carried out by B. E. Markarian, V. A. Lipovetski, and J. A. Stepanian in 1965-1980 with Byurakan Astrophysical Observatory (BAO) 1 m Schmidt telescope, is an objective-prism (1.5° prism, giving a reciprocal dispersion of 1800 A/mm near H_γ throughout a useful field of $4^\circ \times 4^\circ$) low-resolution (lr) survey which covers about 17.000 sq. deg. of the Northern sky and part of the Southern Sky at high Galactic latitudes defined by $\delta > -15^\circ$ and IbI>15° and segmented in 28 parallel zones. During the observations, various Kodak emulsions were used (IIF, IIAF, IIaF, and 103aF), providing a λ3400-6900 Å spectral range with a 70 Å-wide sensitivity gap at 5300 Å and a spectral resolution of R=96 near H_γ. The limiting photographic magnitude is 17.5 – 18.0 mag. There are a total ∼40,000,000 spectra for ∼20,000,000 objects in the entire survey. The original aim was the search for galaxies with ultraviolet excess (UVX, Markarian et al., 1989). The second part of the FBS (which started in the 1990s) was devoted to the discovery and study of blue stellar objects (BSOs) (Abrahamian & Mickaelian, 1996, and reference therein). Since 1990s, the lr spectroscopic plates of the FBS was used to select faint (fainter than 12 mag in V- band) late-type stars (LTSs, M and carbon (C) stars) at high latitudes. The large spectral range of the FBS is well suited to identify various types of objects, and especially cool M – type or C – type stars. Visual inspection with a magnification of ×15 (using the magnifying glass. before 2007) 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 Å (N-type C stars). Several objects also showing the C_2 bandhead at 4382 Å are probably carbon stars of R- or CH -type. M – type stars can easily be distinguished because of the titanium oxide (TiO) molecule absorption bands at 4584, 4762, 4954, 5167, 5500, 6200 and 6700 Å. There have been 15 lists of FBS LTSs published between 1990-2010. As a result, the first version of the FBS LTSs catalogue was generated (Gigoyan & Mickaelian, 2012).

2. The Digitized First Byurakan Survey Data

All FBS lr spectral plates have been digitized, resulting in the creation of the Digitized First Byurakan Survey (DFBS) data base (Mickaelian et al., 2007). Its lr spectral images are available on the DFBS web portal in Trieste (Italy, accessed via https://www.ia2-byurakan.oats.inaf.it.

*kgigoyan@bao.sci.am, Corresponding author

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All DFBS spectral plates are analysed with the help of standard analysis softwares (FITSView and SAOImage ds9). This visualization allows us to detect very red and faint candidate C and M stars close to the detection limit in each DFBS plate (particularly, the range ∼6500-6900 Å for the very late subclasses of the N-type and M-type stars, Gigoyan et al., 2008, 2009, 2010, 2011, 2012a, 2019a, Kostandyan et al., 2017) and to perform a better selection of red objects using the possibilities of the analysis softwares compared to the eye-piece search used before (Gigoyan et al., 2001). The second and also very significant advantage is using the image analysis softwares for comparatively bright (m_v ∼12.0-13.0 mag) early-type carbon stars for which in the blue part of the low-resolution spectra the C_2 absorption bands are not easy to detect due to saturation. Such visualization allowed to detect additional 426 new faint objects, 27 C stars of early and late-subtypes, and also 399 stars of late-subclasses M.

The second version of the "Revised And Updated Catalogue of the First Byurakan Survey of Late-Type Stars", containing data for 1471 M and C stars (130 C-type Stars, 1100 M-type giants, and 241 M dwarfs) was generated (Gigoyan et al., 2019b, CDS /SIMBAD VizieR catalogue J/MNRAS/489/2030/catv2).

Figure 1 presents the DFBS lr 2D spectral shapes for early and late-subclasses of the C and M stars, showing TiO and C_2 molecule absorption bands.

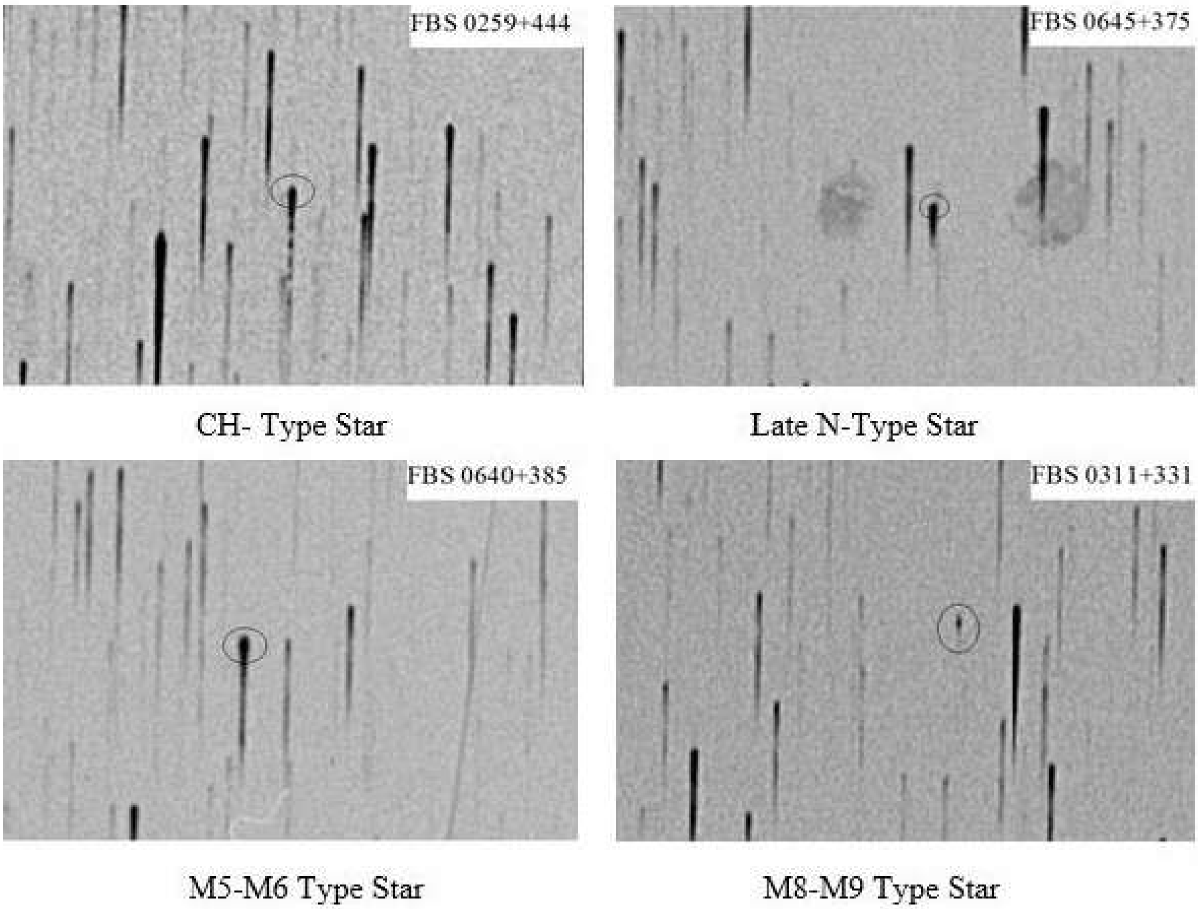

Figure 1. DFBS lr 2D spectral shapes for two FBS M and C stars.

The user interface (the DFBS portal at https://www.ia2-byurakan.oats.inaf.it in Trieste) presently allows two operations: "Get Image" and "Get Spectra". Objects may be selected by USNO-A2 catalogue B and R photometry. The 2D images can also be downloaded by selecting a check box.

Figure 2 illustrate the operation "Get Spectra" showing the list of objects in radius 10 arcmin and an extraction of a given spectrum (on the right) for CH – type carbon star FBS 0259+444. Spectra for this object in the range λ7550−8000 Å were obtained with the Haute Provence 1.93-m telescope (OHP, France), equipped with the CARELEC spectrograph and 512 × 512 (27μm×27μm) pixels Tektronix CCD camera as detector. A 1200 line/mm grating was used, providing a resolution of about of 0.89 Å/pixel (Gigoyan et al., 2001).

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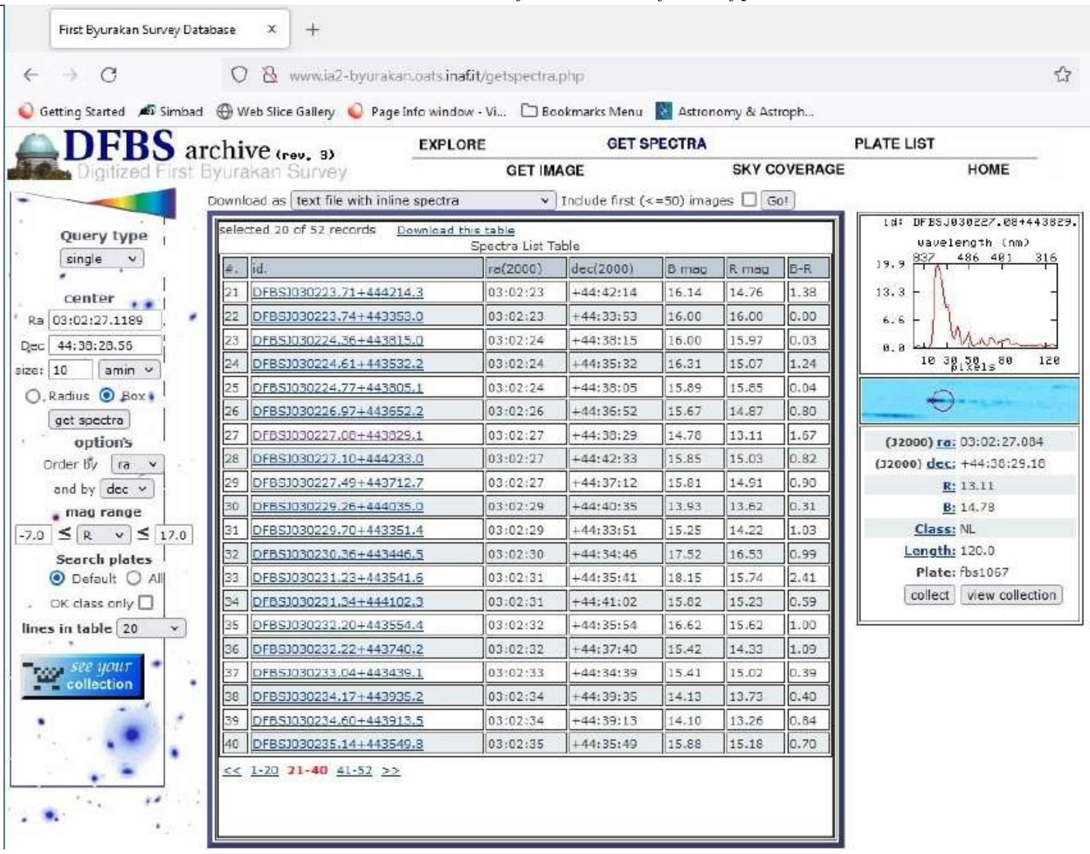

Figure 2. The operation "Get Spectra" showing the list of DFBS objects and an bSpec extraction of a spectra of FBS 0259+444 (2D image on the right, where C_2 molecule absorption bands are very well expressed, identification is DFBS J030227.08+443829.1, USNO A2 catalogue data are: R = 13.11 mag., B = 14.78 mag., B - R = 1.67 mag., DFBS plate No 1067).

3. Spectroscopic Observations

Moderate-resolution CCD spectra were obtained for a large fraction of the FBS LTSs at different epochs and with various telescopes. Optical spectra were obtained with the Byurakan Astrophysical Observatory 2.6-m telescope (BAO, Armenia, spectrographs UAGS, ByuFOSC2 and SCORPIO), the Observatory de Haute Provence (OHP, France) 1.93-m telescope (CARELEC spectrograph), the Cima-Ekar 1.83-m telescope of the Padova Astronomical Observatory (Italy), and the 1.52-m Cassini telescope of the Bologna Astrophysical Observatory (Italy) as describes in Gigoyan et al. (2019b). These spectra allowed to confirm the carbon-rich(C-rich) or oxygen-rich (O-rich) nature of our selected stars.

Figure 3-5 presents consequently the 2.6-m BAO telescope medium-resolution ByuFOSC2 (Figure 3) and SCORPIO (Figure 4) spectra, and OHP 1.93-m CARELEC spectra (Figure 5) for FBS LTSs as illustrative examples.

Moderate-resolution CCD spectra for more than 400 FBS LTSs were secured by LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope) observations (LAMOST DR5, spectra available on-line at http://dr5.lamost.org/search/). This data set allows an independent verification of our classification, and the O-rich nature could be confirmed for more than 90 percent of the FBS M–giants.

Figure 6 presents the LAMOST moderate-resolution spectra for four FBS M giants.

4. Variability Study Of The FBS M Giants.

To determine the variability types of the FBS M-giants, we exploit data from two primary sources, namely the Catalina Sky Survey (CSS, second public data release CSDR2, accessed via http://nesssi.cacr.caltech.edu/DataRelease/) and the All-Sky Automated Survey for Supernovae (ASAS-SN, accessed via https://asas-sn.osu.edu/variables/, Jayasinghe et al. (2018), Kochanek et al. (2017), Shappee et al. (2014)). The CSS comprises two main parts surveying the Northern (Drake et al., 2014) and Southern (Drake et al., 2017) sky, respectively. Both surveys were analyzed by the Catalina Real-Time Transient

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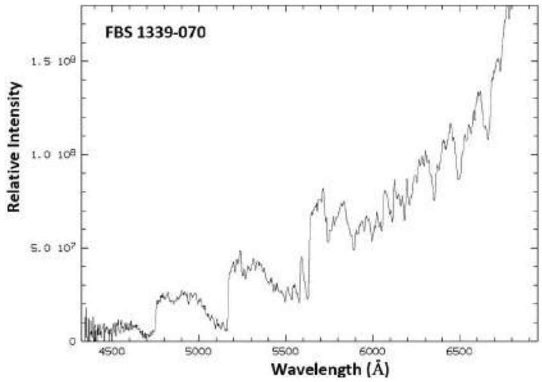

Figure 3. 2.6-m BAO telescope ByuFOSC2 moderate-resolution CCD spectra for carbon star FBS 1339-070 in the range λ4300-6900 Å, obtained on April 6, 1999.

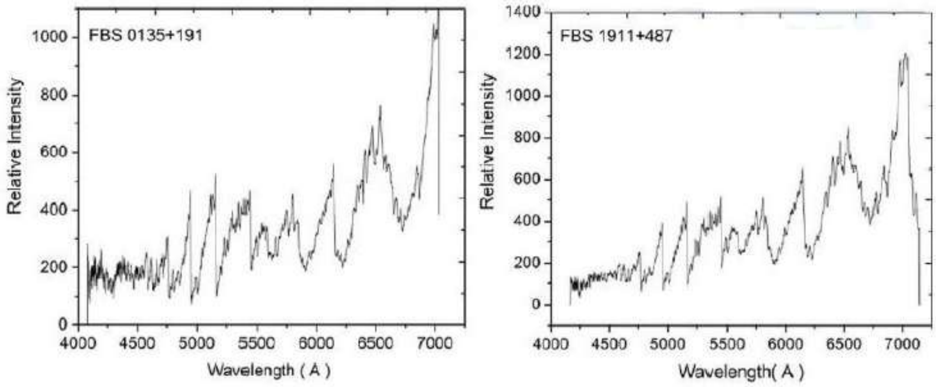

Figure 4. 2.6-m BAO telescope SCORPIO medium-resolution CCD (EEV 42-40) spectra for two M giants FBS 0135+191 and FBS 1911+487, obtained on November 12, 2018.

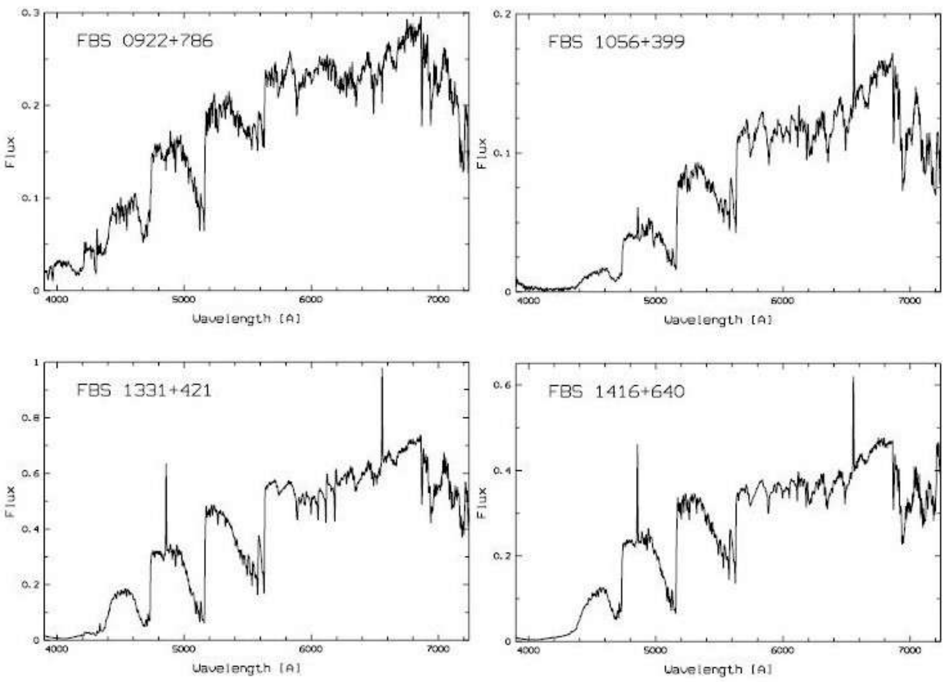

Figure 5. OHP 1.93-m telescope CARELEC medium-resolution spectrograph CCD (EEV 42-20, 13.5μm×13.5μm pixels) spectra in the range λ4000-7200 Å for four FBS carbon stars, obtained on 26-29 June, 1998.

Survey (CRTS) in search for optical transient (V < 21.5 mag) phenomena. The ASAS-SN project as an all-sky optical monitoring to photometric depth V≤17.0 mag providing variability types, periods, and

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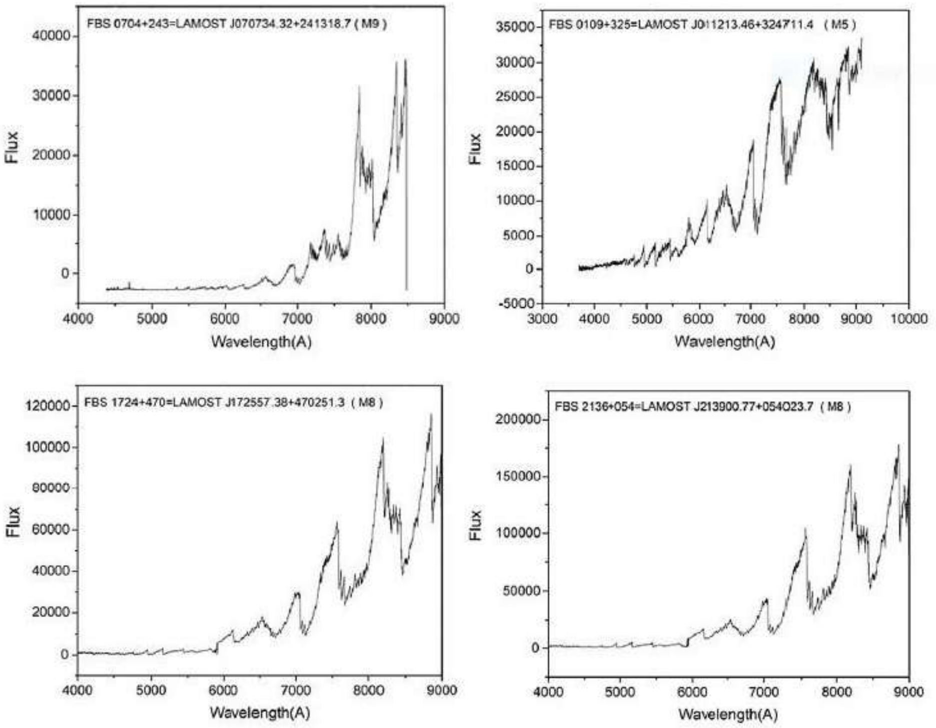

Figure 6. LAMOST moderate-resolution CCD spectra for a sample of FBS M giants.

amplitudes to the FBS M-giants.

Our final sample consists of 690 SR (Semi-Regular)-type, 300 L-type (irregular) and 110 Mira-type variables (Gigoyan & Kostandyan, 2021). A separate paper is devoted to variability study of the FBS N-type Asymptotic Giant Branch (AGB) carbon stars (Gigoyan et al., 2014).

5. Parameters Derived From Gaia Data. 2MASS And Gaia EDR3 Photometry

Gaia EDR3 (Gaia Collaboration et al., 2021) contains astrometry, three-band photometry, radial velocities, effective temperatures, and information on astrophysical parameter and variability for approximately 1.8 billion sources brighter than G = 21.0 magnitude. All FBS M giants (Gigoyan et al., 2019b) were cross-matched with Gaia EDR3 catalogue (CDS VizieR catalogue I/350/gaiaedr3) sources. Combining 2MASS (Skrutskie et al., 2006) Near-Infrared (NIR) and Gaia photometric information, Lebzelter et al. (2018) constructed a new diagram as an analysis tool for red giants. For this, they combined Wesenheit functions in the NIR and in the Gaia range. The 2MASS H and Ks NIR Wesenheit function is defined following (Soszyński et al., 2005) as:

$$W_{Ks,J-Ks} = Ks - 0.686(J - Ks) \tag{1}$$

where as the Wesenheit function for Gaia BP and RP magnitudes (Lebzelter et al., 2018) is defined as:

$$W_{RP,BP-RP} = G_{RP}–1.3(G_{BP} - G_{RP}) \tag{2}$$

In Figure 7 we show the application of this diagram to spectroscopically confirmed FBS M and C giants with Gaia EDR3 distances (Bailer-Jones et al., 2021, CDS VizieR Catalogue I/352/gedr3dis).

Six distinct groups of red giants with their boundaries had been identified therein by Lebzelter et al. (2018). Lebzelter et al. (2018) showed that these groups correspond to low-mass, untermediate-mass, and massive O-rich AGB stars as well as RSG, C-stars and extreme C-rich AGB stars (Gigoyan et al., 2021).

The majority of the FBS giants occupies the region of low mass, oxygen-rich AGB stars in this diagram. It thus seems likely that the FBS sample primarily consists of stars with M<2M$_{Sun}$. The lack of the RSG and massive AGB stars among the sample of the FBS M giants is evident.

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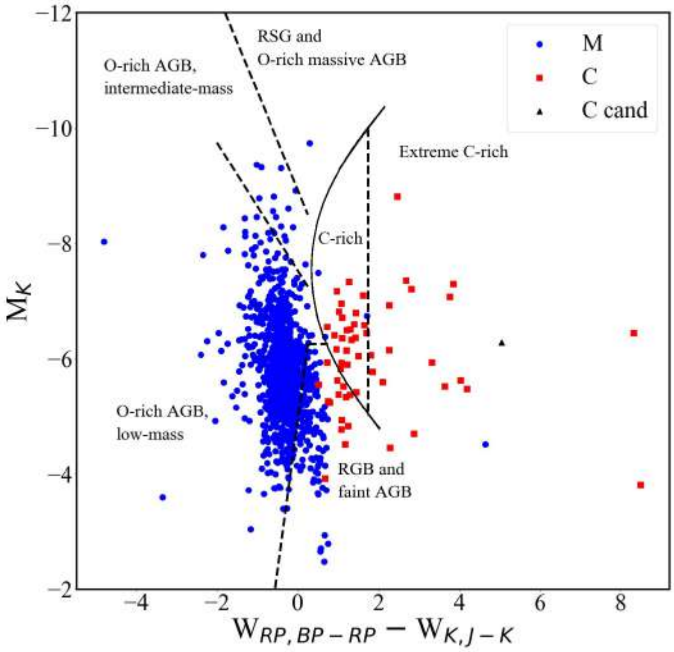

Figure 7. $W_{BP,BP-RP} - W_{Ks.J-Ks}$ versus M(K) diagram for FBS M and C giants. Approximate boundaries of regions (a)(low-mass O-rich AGB stars), (b)(C-rich stars and "Extreme" C-rich stars), (c)(intermediate-mass O-rich AGB stars), and (d)(O-rich massive AGB stars and Red Supergiants-RSG) identified for LMC stars in Figure 1 and 3 by Lebzelter et al. (2018) have been reconstructed.

Infra-Red (IR) astronomical databases, namely, IRAS, 2MASS, WISE, and Spitzer, are used to analyze photometric data of 126 FBS carbon stars (Gigoyan et al., 2017).

6. FBS M Dwarfs

A total of 235 M-type stars (16 per cent of all FBS M stars detected) are classified as dwarfs. They show detectable **proper motions (PM)** and NIR colours typical for M dwarfs. Figure 8 presents 2MASS J-H versus H-Ks colour-colour plots for all 1471 FBS M-and C-type stars, indicating their luminosity classes. M dwarfs are denoted by red squares.

A special interest present the extremely high proper motion star FBS 0250+167 (Gigoyan et al., 2003). This object was detected on FBS plate No117 (Kodak -IIAF, obtained on 1-m Schmidt telescope 13 November, 1969). In our XIV-th list of the LTSs, we present this object as M7-M8 subtype star (Gigoyan et al., 2003).

Figure 9 presents the DSS1 R and DSS2 R finder charts, and lr 2D spectral shape of the FBS 0250+167 on the plate No117.

Figure 10 present the direction of the motion of the high proper motion star FBS 0250+167, which was constructed, using DSS1, DSS2, DFBS Plate No117data, also Gaia EDR3 high accurate astrometric data.

The study of all new discovered FBS M dwarfs from the Gaia EDR3 point of view is now being carried out and the results will be appear soon (Gigoyan et al., in prep.).

7. New Carbon And M Stars Candidates

As it was mentioned above (Chapter 2), the data visualization (zooming the digitized images, changing the scale parameters of the DFBS plates, et al.) with help of the analysis softwares FITSView and SAOImage ds9 allows to detect very red and faint M and C stars and candidates close to the detection limit in each DFBS plate. Using the both softwares, we detected 1471 M and C stars. We selected also a huge amount of new faint candidates, which need to confirm by moderate-resolution spectroscopy. They are:

1. Candidate faint N – type AGB and M – type giants, for which on the DFBS plates only very short spectra (wedge-like) in the range ~6600-6900 Å is visible, no C_2 and TiO **molecule absorption** bands are detectable. Some part of the such faint candidates can be dwarf M stars also (for example,

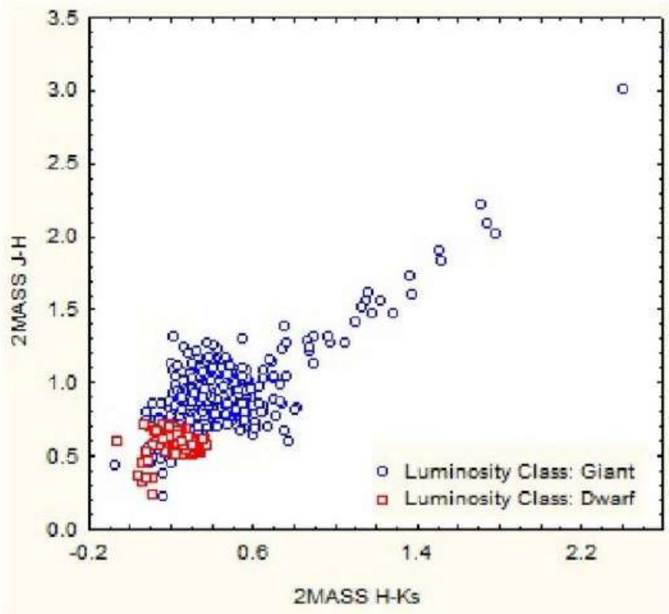

Figure 8. The 2MASS J-H versus H-Ks colour-colour diagram for all 1471 FBS LTSs. Blue circles represents giants, and red squares represent dwarfs (dwarfs are M stars only).

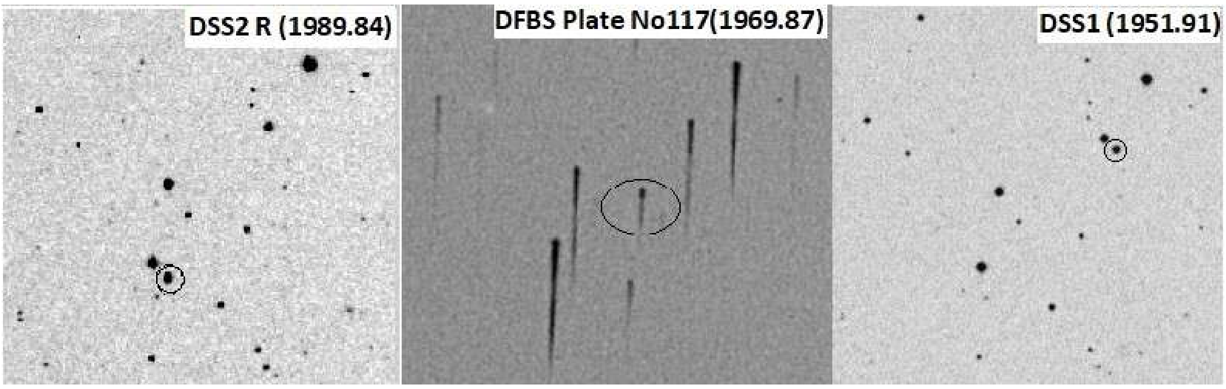

Figure 9. DSS1 R and DSS2 R, finder charts, also DFBS lr 2D spectral shape on the plate No117 for high proper motion star FBS 0250+167.

DFBS J072820.67+310019.7 = LSPM J0728+3100E, which is **high** proper motion object, Lépine & Shara (2005), CDS SIMBAD VizieR catalog I/298. "LSPM-North Catalog", which is M6-M7-sybtype dwarf star, B=16.20, R=14.33, B-R = 1.87). We confirm the C-rich nature for some amount of such candidates by moderate-resolution CCD spectroscopy (Gigoyan et al., 2012b).

2. The second group of the new faint candidates are early-type carbon stars (usually they are CH or R-type carbon stars, also dwarf carbon star (dC) candidates), for which C_2 molecule absorption bands at 5636, 5165, 4737, and 4382 Å are very hardly detectable (or practically no detectable) on the DFBS spectra with help of the FITSView and SAOImage ds9 visualization softwares, because of their faintness (usually they are 1.0 mag. brighter or are close to the detection limit of each DFBS plates).

As illustrative examples, in Figure 11 we present bSpec extraction (one-dimensional and 2D spectrum) for the new CH star candidate DFBS J024615.25+484150.9 and for candidate dC star DFBS J161647.00+633404.3 only. Because of the faintness, C_2 absorption bands are hardly visible on the DFBS plates.

Table 1 presents some important Gaia EDR3 data for two new C star candidates.

Adopting apparent visual magnitudes V=15.29 and V=15.77 for DFBS J024615.25+484150.9 and for DFBS J161647.00+633404.3 (UCAC4, CDS VizieR catalogue I/322A), the absolute V-band magnitude can be estimated M(V) = +1.17 and M(V) = +9.5, respectively. These values are typical for CH (M(V)= +1.17) and for dC (M(V) = +9.5) carbon stars.

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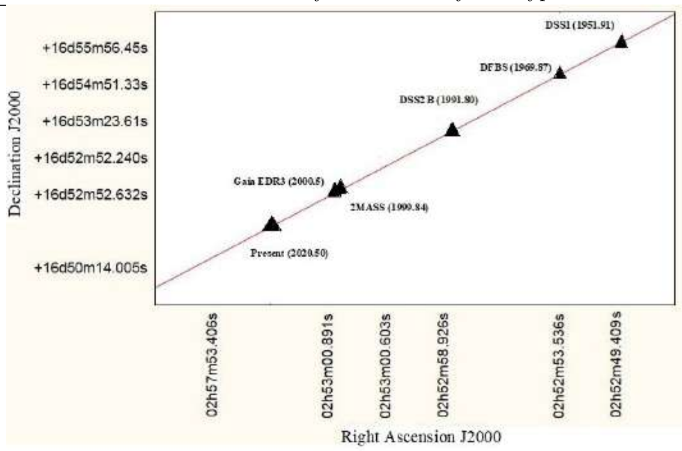

Figure 10. Direction of the motion of the high proper motion (PM = 5.122 ″/yr) star FBS 0250+167, which was found due to DFBS plate No117. The Gaia EDR3 parallax value of 260.988 mas (pmRA = 3429.083 mas/yr, pmDec = - 3805.541 mas/yr, G = 12.263 mag) placed this star at a distance r = 3.83 pc.

Table 1. Gaia EDR3 Data For Two New DFBS Early-Type C Star Candidates

DFBS Number	Gaia EDR3 Name	Gmag	BP mag	BP-RP mag	R (kpc)
J024615.25+484150.9	438564097055438720	14.28	15.41	2.17	6.641±1.0
J161647.00+633404.3	1629378311406218240	15.08	16.05	1.94	0.185±0.0072

8. Conclusion And Future Programmes

All DFBS low-resolution spectral plates have been analysed for comparatively faint late M -type and C-type stars. The "Revised And Updated FBS LTSs Catalogue. Version 2" lists a large number of completely new objects (1471 stars), **which extended very significantly the census of M** giants, faint N-type Asymptotic Giant Branch carbon stars, CH-type carbon giants at high Galactic latitudes, and M dwarfs in the Solar vicinity up to 16.0-17.0 mag. in the visual. We have performed cross-correlations with DFBS, USNO-B1.0, 2MASS, **ALLWISE**, IRAS PSC/FSC AKARI, ROSAT, SDSS catalogue data (Gigoyan et al., 2019b). Gaia EDR3 broadband G magnitudes are in the range 9.4<G<18.2 for C stars. **Large fraction of the new N-type FBS C stars discovered belong to the Galactic Halo population and are considered as Faint High Latitude Carbon stars (FHLCs, R > 13.0 mag., IbI > 13.0 mag., see definition of Margon et al., 2002, Totten & Irwin, 1998). Consequently, their kinematical characteristics provide information on the properties and mass of the Galactic Halo. They are not further than 25.0 kpc from the Sun. Two objects among the FBS C stars deserve maximum attention. They are FBS 1502+359 and FBS 2213+421. Both its medium-resolution spectrum and its very large color index suggests that these objects are surrounded by a dusty envelopes. The FBS 1502+359 is a Semi-Regular (SR) variable C star (Gigoyan et al., 2001, 2014). The second object FBS 2213+421 is a R CrB-type variable with initial mass ~2M$_{Sun}$ (Rossi et al., 2016). Most of our FBS sample of M giants are found at typical distances of 1 kpc above or below the Galactic plane. Spectroscopically confirmed FBS O-rich and C-rich giants show the same separation in the Gaia -2MASS -diagram, as long-period variables (LPVs) in the Large Magellanic Cloud (Lebzelter et al., 2018). The discrimination between O-rich and C-rich objects becomes even more visible when using the W$_{RP,BP-RP}$ − W$_{Ks,J-Ks}$ versus Gaia BP-RP color or 2MASS J-Ks versus BP-RP. This offer the opportunity to use the difference of Wesenheit indices W$_{RP,BP-RP}$ − W$_{Ks,J-Ks}$ also for chemistry classification in sample with unknown distances while losing the ability of the Gaia -2MASS diagram to separate the stars according to mass (Gigoyan et al., 2021).**

Near 16 percent of all FBS M stars detected are classified as dwarfs. They show detectable proper motions and NIR colors typical for M dwarfs. Their distances are in the range 3.8 pc<r<1000 pc. Based on DFBS lr spectral plates, the spectral types as M dwarfs we presented for many known proper motion

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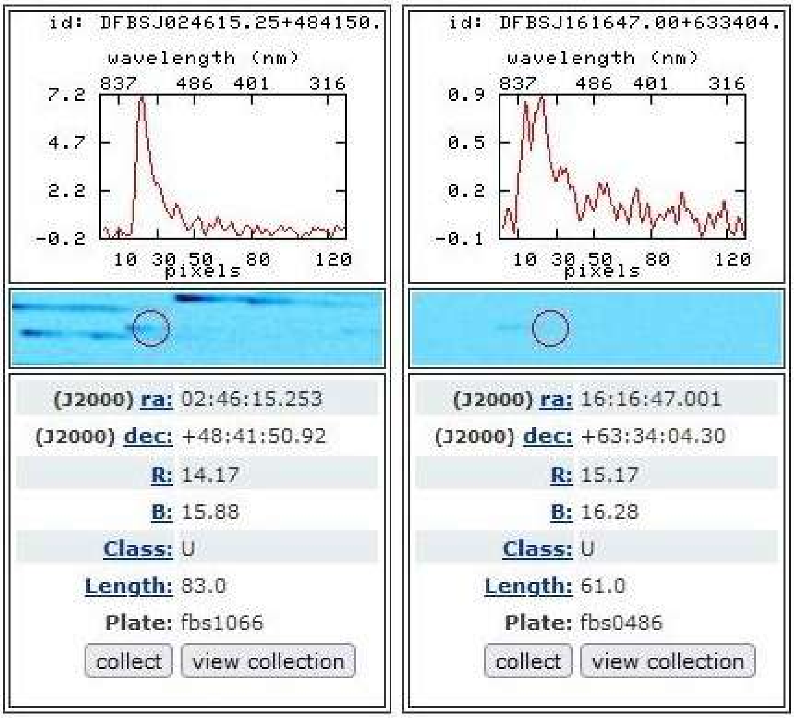

Figure 11. bSpec extraction of the DFBS low-resolution spectra for new CH star candidate DFBS J024615.25+484150.9 and for candidate dC star DFBS J161647.00+633404.3, which show high proper motion **(PM = 124.128 mas/yr)**.

objects for the first time (Gigoyan et al., 2019b).

Visual inspection of the objects with help of these softwares, resulted to discovery of a huge amount of new M and C star candidates also in the DFBS lr spectral plates. Some fraction of the new detected faint candidates show double peaked spectral energy distribution (SED), indicating the existence of the dusty envelopes around these objects. Moreover, similar SED show also part of the detected faint objects, which are M dwarf candidates, i. e. they show high PM and NIR J-H and H-K colors, typical for M dwarfs (Bessell & Brett, 1988). Most probably such new candidates are M dwarfs with debris discs around and IR excess emission (Sgro & Song, 2021). All they need in future by moderate-resolution spectroscopic confirmations.

Meanwhile, some amount of the new and faint LTSs candidates can be missed, because of variety of reasons. Therefore, we plan in near future to use machine learning algorithm, to select faint LTSs candidates using a definite spectroscopic criterii.

In 2011, Markarian survey and its digitized version, DFBS, entered **UNESCOs Documentary Heritage "Memory of the World" International Register** (Mickaelian et al., 2021).

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