Investigation of DFBS late type stars at high galactic latitudes.

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Abstract

We study in this thesis relatively bright late-type giants found in the First Byurakan Survey (FBS) data base.We present the 2nd version of the catalogue of FBS LTS with new data (FBS LTS v2), 1471 objects. It is a homogeneous and complete database for high- Galactic late-type stars, including M and C types. Since 2007, all FBS low-resolution spectral plates are digitized. All DFBS spectral plates are analyzed with FITSView and SAO Image ds9 and numerous relatively faint LTS were discovered. We have made cross-correlation with DFBS, USNO-B1.0, 2MASS, AllWISE, IRAS PSC/FSC, AKARI, ROSAT BSC/FSC, GCVS, SDSS and added updated SIMBAD data. For numerous new detected objects, we present accurate DSS2 positions, approximate spectral subtypes refined from the DFBS low-dispersion spectra, luminosity classes estimated from 2MASS colours, and available proper motions for 1471 FBS LTS. The Revised and Updated Catalogue v2 lists a large number of completely new objects, which promise to extend very significantly the census of M giants, faint N-type AGB carbon stars, CH-type carbon giants at high Galactic latitudes, also M dwarfs in the Solar vicinity up to 16.0m-17.0m in visual. Phase dependent light-curves from large sky area variability data bases such as Catalina Sky Survey (CSS) and All-Sky Automated Survey for Supernovae (ASAS-SN), and the early installment of the third *Gaia* data release (Gaia EDR3) photometric and astrometric data have been used to characterize our sample of 1100 M-type giants found and 130 C-type stars at high latitudes. We show the behaviour of our sample stars in a *Gaia* DR2 color–absolute magnitude diagram (CaMD), the *Gaia*-2MASS-diagram, including two alternative versions, and the logP-K-diagram. In this way we explore the potential of these diagrams and their combination for the analysis and interpretation of datasets of LPVs. We show the possibility to classify stars into M- and C-types and to identify the mass of the bulk of the sample stars.

Keywords: *carbon stars: surveys: late – type stars*

1. Introduction

The First Byurakan Survey (FBS, known also as a Markarian survey) is an objective – prism low – resolution (lr) survey. It is performed with the Byurakan Observatory 1 m Schmidt telescope, which covers about 17.000 sq. deg. of the Northern sky and part of the Southern sky at high Galactic latitudes defined by δ > -15^o and IbI > 15^o. The FBS was originally conducted for galaxies with ultraviolet excess (UVX) Markarian et al. (1989). Since 1990s, the lr plates of the FBS was used to select comparatively faint (fainter than 12 mag. in visual) late – type stars (LTS, M and carbon (C) stars) at high latitudes. The large spectral range of the FBS (λ 3400 – 6900 Å) is well suited to identify cool M – type or C – type stars. C stars can be identified through the presence of Swan bands of C_2 molecule at 4737, 5165, and 5636 $\AA$ (N – type C stars). Several objects showing the C_2 band-head at 4382 Å are early – type C stars (R or CH type stars). M – type stars can easily be distinguished because of the titanium oxide (TiO) molecule absorption bands at 4584, 4762, 4954, 5167, 5500 and 6200 $\AA$ Gigoyan & Mickaelian (2012). The eye – piece search (with magnification 15x) near 2000 FBS lr plates resulted to discovery 1045 new LTS. On the base of this selection the "Revised And Updated

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Catalogue of the First Byurakan Survey of LTS" was generated Gigoyan & Mickaelian (2012). Now the entire plate set of the FBS has been digitized (1874 plates for 1139 fields) leading to the Digitized First Byurakan Survey (DFBS) Mickaelian et al. (2007) (online at http://byurakan.phys.uniroma.it or http://www.ia2-byurakan.oats.it /).

We present in this this thesis the 2nd revised and updated version of the FBS LTS Catalogue at high Galactic latitudes, which is a comprehensive list of 1471 objects (compared to 1045 objects in FBS LTS v1),the methods of selecting and spectral classification of the late type stars of the First Byurakan Survey, the photometric study of the FBS late type stars in the infrared range, GAIA study of the FBS late type stars and the variability study of the FBS late type stars based on CATALINA, NSVS and ASAS-SN. The CATALINA and LINEAR long periodic variables are also studied.

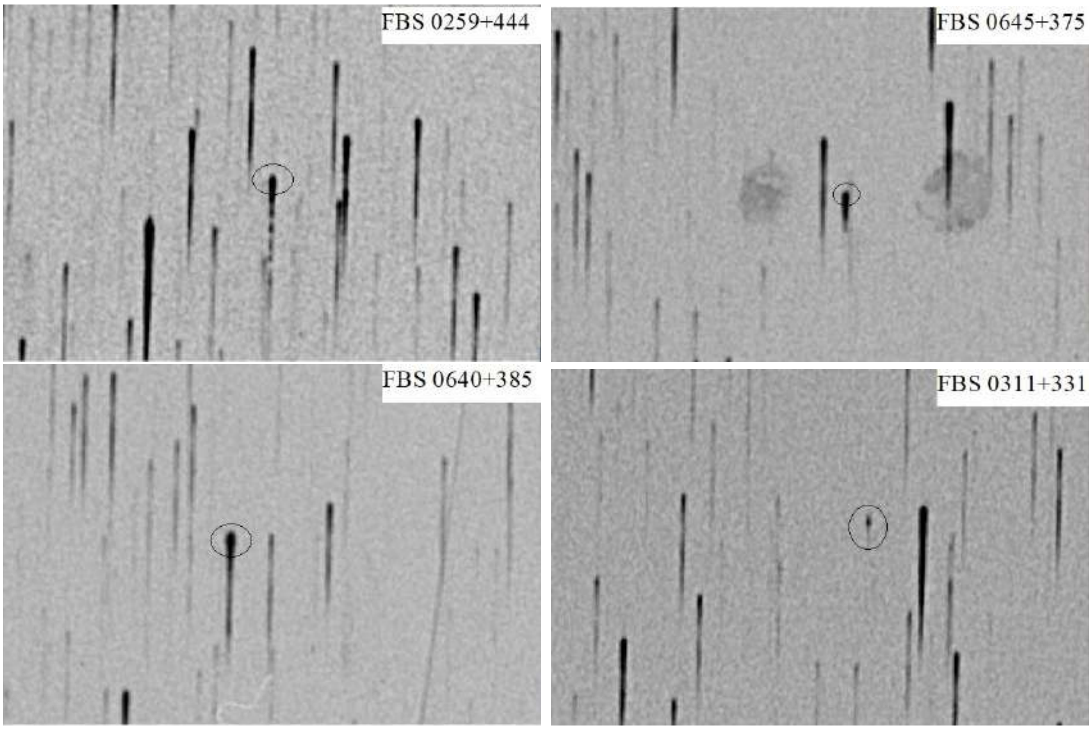

Figure 1. Two-dimensional low-resolution spectral shapes for the newly discovered DFBS objects.

2. Revised and updated catalogue of the First Byurakan Survey late-type stars. 2nd edition

All DFBS spectral plates (near 1800) are analyzed with the help of standard image analysis software (FITSView and SAOImage ds9). This visualization allows us to detect very red and faint candidate stars close to the limit in each DFBS plate (particularly, the range ~6500-6900 Å for the very late subclasses of the N-type and M-type stars and to perform a better selection of red objects using the possibilities of the analysis software (zooming the frame region et al.) compared to the eye-piece (lens) search used before. The second and very significant advantage is using the image analysis software for comparatively bright ($m_v \sim 12 - 13^m$) early type C stars, for which in the blue part of the low-resolution spectra the C_2 absorption bands are not easy detect due to saturation. Such visualization allowed us to detect additional 426 new faint objects, 27 C stars of early and late-subtypes, and also 399 stars of M classes.

Figure 1 shows examples of two-dimensional low-resolution spectral shapes for the newly discovered DFBS objects .

For FBS LTS medium-resolution spectra were obtained on diferent epochs with the BAO 2.6m telescope (UAGS, ByuFOSC2 and SCORPIO spectrographs; Abramyan & Gigoyan (1993)). C - rich nature for FBS candidates were confirmed also by moderate and high-resolution CCD spectroscopy,

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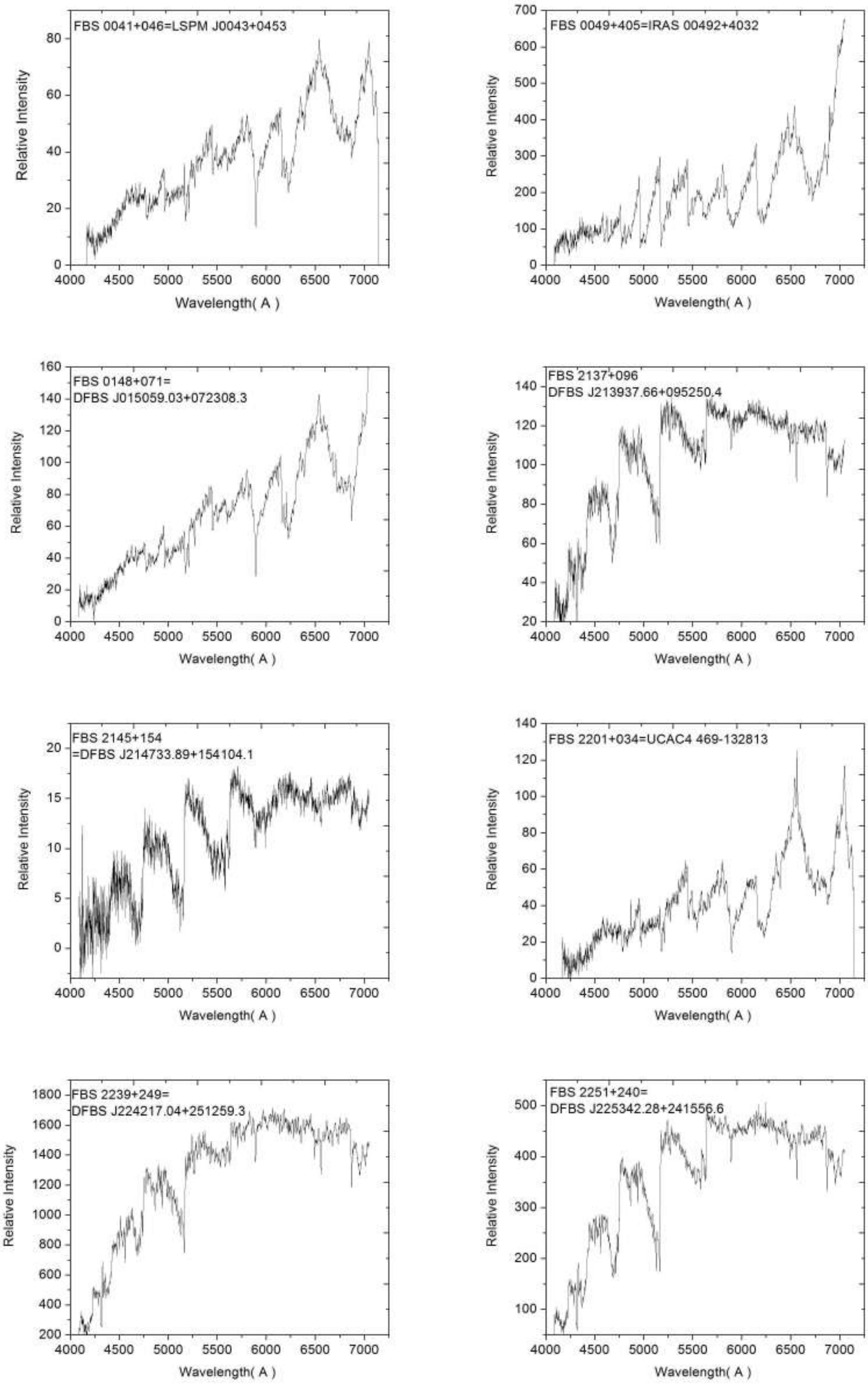

Figure 2. 2.6 m BAO telescope moderate-resolution CCD spectra for objects Table 1

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Table 1. Data for 8 FBS Late-Type Stars

FBS Number	Other Association	Exp. time (sec)	Sp. class	Lum. Cl.
0041+046	LSPM J0043+04531	300	M	Dwarf
0049+405	IRAS 00492+40322	120	M	Giant
0148+071	DFBS J015059.03+072308.33	600	M	Dwarf
2137+096	DFBS J213937.66+095250.43	300	C-CH	Giant
2145+154	DFBS J214733.89+154104.13	600	C-CH	Giant
2201+034	UCAC4 469-1328134	120	M	Dwarf
2239+249	DFBS J224217.04+251259.33	120	C-CH	Giant
2239+249	DFBS J224217.04+251259.33	120	C-CH	Giant

obtained with the Observatory de Haute-Provence (OHP, France) 1.93m telescope (CARELEC spectrograph; Gigoyan et al. (2001)). For some amount of FBS C stars medium-resolution CCD spectra also were obtained at the Cima-Ekar 1.83m telescope of the Padova Astronomical Observatory (Italy) equipped with the Asiago Faint Objects Spectrometer and Camera (AFOSC) and with the 1.52m Cassini telescope of the Bologna Astronomical Observatory at Loiano (Italy) equipped with the Bologna Faint Objects Spectrometer and Camera (BFOSC; Gigoyan et al. (2008)). All CCD observations, confirms reliability of our preliminary low-resolution spectral class determinations on the FBS plates. Optical spectra for some number of the new detected LTS spectra were obtained also on 8/9 September 2016 with the SCORPIO spectrograph and EEV 42-40 2048x2048 CCD (pixel size is 13.5m, resolution $\sim$ 6Å spectral range 4000-7250 Å using 600 lines mm^{-1} grism. Observations were reduced using standard MIDAS techniques. These observations are summarized in Table 2, where column 1 presents the FBS Number; column 2-other associations in SIMBAD data base, column 3-exposure time, column 4 and 5-spectral class and luminosity class of the objects. Figure 2 presents 2.6m BAO telescope moderate-resolution CCD spectra for some objects of the Table 1.

As a result, a second version of the FBS catalog of late-type stars was generated. It consists of 1471 late-type stars, including the spectral types and luminosities of these stars. Accurate optical positions for all 1471 FBS LTS determined in the POSSI (DSS1) and POSSII (DSS2) digitized sky surveys made it possible to correctly cross-correlate the sample with all available modern astronomical catalogues and data bases, namely USNO-B1.0, SDSS DR15, Gaia DR2, 2MASS, AllWISE and IRAS PSC/FSC. The catalog is available at https://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=J/MNRAS/489/2030.

3. Investigation of infrared photometry of late type stars from FBS

Photometric studies of late-type DFBS stars were carried out in the infrared range. Two-color diagrams of 2MASS, IRAS, AKARI9 and WISE were constructed, which once again confirm the accuracy of spectroscopic classification. Class M dwarfs are very well separated on the 2MASS JHK color-color diagram in the infrared (NIR).

Figure 3 presents the 2MASS *J-H* versus H-K_s colour-colour diagrams for all 1471 FBS LTS. Objects having *J-H* $>$ 0.8 and H-K_s $>$ 0.2 in the colour-colour diagram, usually are AGB stars. M dwarfs show proper motions and are very well separated on *JHK* Near-IR colour-colour diagram usually *J-H* $<$ 0.7 and H-K_s $>$ 1.5, see paper for more details (Bessell & Brett, 1988). 235 stars (out of 1471) show significant proper-motions and are classified as M dwarfs in FBS new LTS Catalogue.

Figure 4 presents the WISE colour-colour diagrams for all 1471 FBS LTS. On the WISE two-color diagram CH, R carbon stars have the same color as early M-class stars. M-class giants and dwarfs - appear on the diagram in the same compact range. Color indices criteria based on WISE data allow the selection of AGB stars with gas and dust envelopes and to distinguish between C and M stars.

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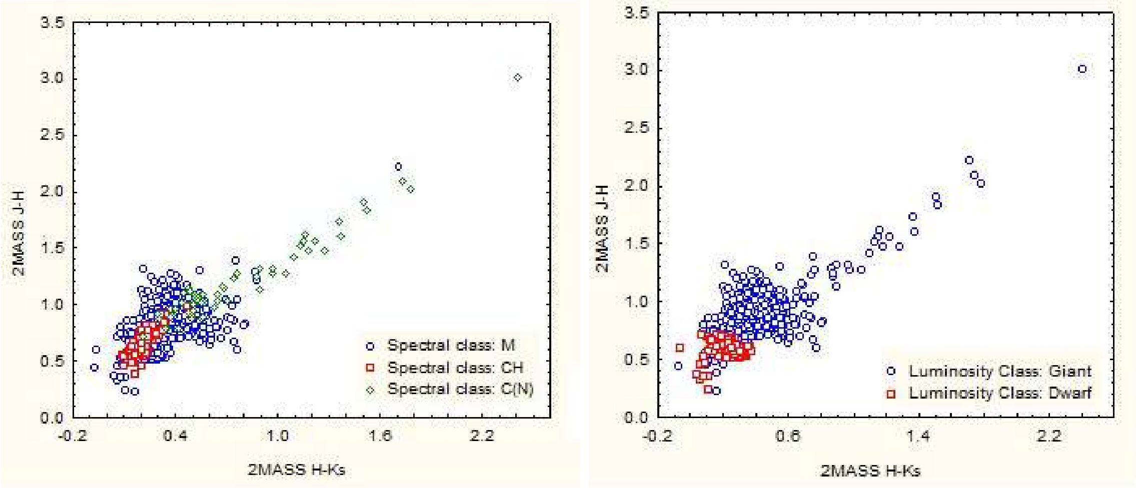

Figure 3. The 2MASS *J-H* versus *H-*K_s colour-colour diagrams for 1471 FBS LTSs stars.

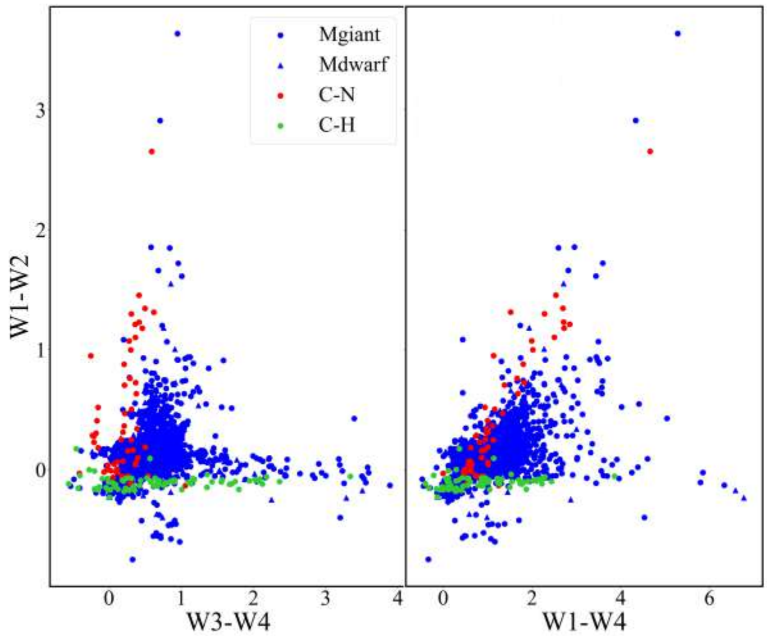

Figure 4. The WISE colour-colour diagrams for 1471 FBS LTSs stars.

4. Investigation of *Gaia* photometry of late type stars from FBS

The *Gaia* study was also conducted. The color - absolute magnitude and Teff - the absolute magnitude of the Hertzsprung–Russell diagram were plotted based on the distance data. Figure 5 show positions on colour – absolute M_G magnitude Gaia DR2 G – band absolute magnitude Hertzsprung – Russell diagram for 127 FBS C stars, also for near 150 M dwarfs from the "FBS Late – Type Stars Catalogue" Gigoyan et al. (2019). All N - type AGB stars are distributed in the brightest region, where Long – Period Variables (Miras, Semi – Regular variables, slow irregular variables, and small – amplitude red giant) are located and Figure 2 and 3 by Gaia Collaboration et al. (2019). Absolute G – band magnitude was estimated via the usual equation Gaia Collaboration et al. (2019);

$$M_G = G - 5Logr + 5 - A_G, \quad (1)$$

Combining 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 J and Ks NIR Wesenheit function is defined as Soszynski et al. (2005);

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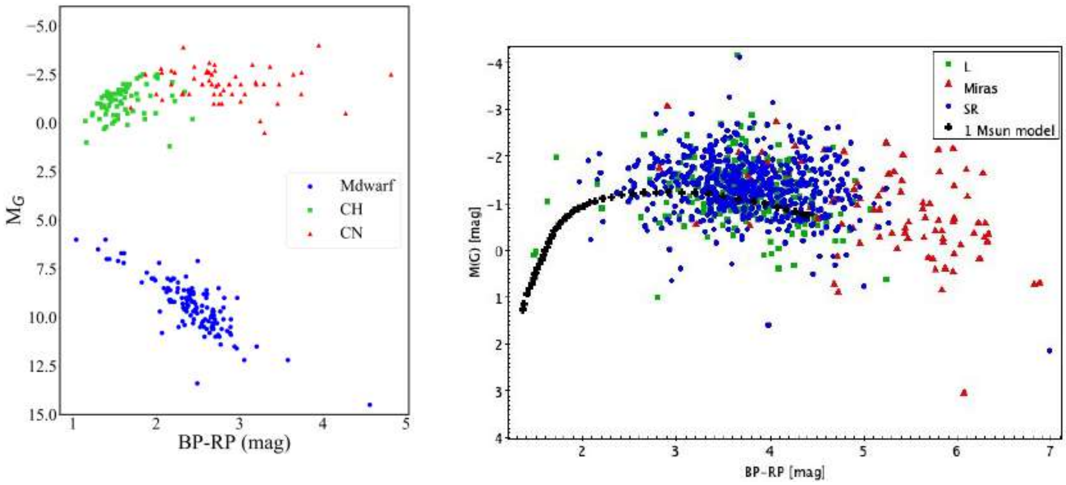

Figure 5. The Hertzsprung–Russell diagrams of FBS C stars and M gaints.

$$W_{K,J-Ks} = Ks - 0.686(J - Ks), \tag{2}$$

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

$$W_{RP,BP-RP} = G_{RP} - 1.3(G_{BP} - G_{RP}) \tag{3}$$

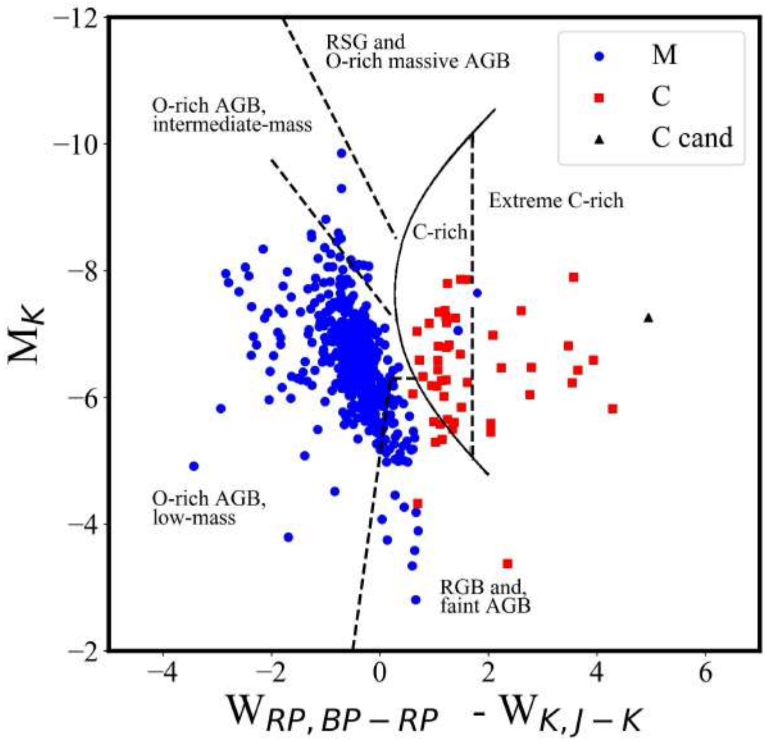

Figure 6. $W_{RP,BP-RP}$ - $W_{Ks,J-Ks}$ versus M_{Ks} diagram for FBS M and C giants.

In Figure 6 we show the application of this diagram to spectroscopically confirmed M and C giants with *Gaia* distances within our sample. Lebzelter et al. (2018) constructed this diagram for Large Magellanic Cloud (LMC) long period variables (LPVs) and demonstrated that it allows to identify subgroups among Asymptotic Giant Branch (AGB) stars according to their mass and chemistry. Six

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distinct groups of red giants with their boundaries had been identified therein (for the definition of the borders of the groups see Table A.1 in Lebzelter et al. (2018)). For Figure 4, these boundaries were shifted according to the distance modulus of the LMC of 18.45 mag (Elgueta et al., 2016). With the help of synthetic stellar population models (based on the TRILEGAL code, Girardi et al. (2005), Marigo et al. (2017)), Lebzelter et al. (2018) showed that these groups correspond to low-mass, intermediate-mass, and massive O-rich AGB stars as well as RSG (Red Supergiants) and extreme C-rich AGB stars, the specific stellar mass range in each of these groups depending on the stellar metallicity (see Fig. 3 in Lebzelter et al. (2018) for details).

Figure 6 nicely confirms the ability of the *Gaia*-2MASS-diagram to distinguish between M- and C-stars. 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 < 2 $M_{\odot}$. Besides that, the diagram reveals a few candidates for intermediate mass AGB stars. The lack of the RSG and massive AGB stars among the sample of the FBS M giants is clearly evident.

5. Investigation of optical variability of late type stars from FBS

To study optical variability for FBS late-type stars, the basic data coming from the most prominent and wide-area sky were used and considered the CATALINA, NSVS, ASAS-SN, and LINEAR databases. The light curve analysis confirms nine stars as Mira-type variables, 43 as Semi-Regulars (SR) with very well expressed periodicity, and two objects as Irregular (Irr)-type variables for C stars. According to the ASAS-SN light curves, 690 of the giant M stars are classified as SR, 294 stars as L (Irr) variables, and 112 stars as Mira type.

A list of 1184 CRTS LINEAR objects was compiled, for which P ≥ 10 days. It is available at https://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=J/other/Ap/64. Spectral grades approved for over 625 PV. These are class F, G, K and M giants and dwarfs, as well as N-class stars at high galactic latitudes. For a large number of the PVs, we confirm spectral classes for objects presented in the "General Catalogue of Variable Stars: Version GCVS 5.1". Our list should be very useful for future versions of the GCVS. Nearly 100 LPV stars and 25 objects with very large Gaia DR2 BP - RP colors still need to be confirmed spectroscopically, and they will be included in our future observations.

6. Discussion and conclusion

We revised, updated and generated the new version of the FBS LTS catalogue. The second version of the catalogue contains main available data for 1471 objects. In revised catalogue we present DSS1/DSS2 accurate positions, USNO-B1.0 catalogue optical photometry and proper motions, WISE IR photometry, et al. for 1471 objects. Among 1471 objects, 127 are carbon stars of early and late subclasses. 235 LTS are M dwarfs. The remaining objects are M giants. Large number of the FBS LTS are completely new objects, which promise to expand the census of M giants and M dwarfs in the Solar vicinity. Two-color diagrams of 2MASS, IRAS, AKARI9 and WISE were constructed, which once again confirm the accuracy of spectroscopic classification. Class M dwarfs are very well separated on the 2MASS JHK color-color diagram in the infrared (NIR). *Gaia*-2MASS-diagram was constructed. Spectroscopically confirmed FBS O-rich and C-rich giants show the same separation in the Gaia-2MASS-diagram according to their chemistry as the LPVs of the LMC originally used to construct this diagnostic tool, providing another confirmation of its reliability. 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 colour or 2MASS J-Ks versus BP-RP. This offers the opportunity to use the difference of Wesenheit indices $W_{RP,BP-RP} - W_{Ks,J-Ks}$ also for chemistry classification in samples with unknown distances while losing the ability of the Gaia-2MASS diagram to separate the stars according to mass. To study optical variability for FBS late-type stars, the basic data coming from the most prominent and wide-area sky were used and considered the CATALINA, NSVS, ASAS-SN, and LINEAR databases. The light curve analysis confirms nine stars as Mira-type variables, 43 as Semi-Regulars (SR) with very well expressed periodicity, and two objects as Irregular (Irr)-type variables for C stars. According to

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