M GIANTS FOUND IN THE FIRST BYURAKAN SURVEY DATA BASE. V. GAIA DR2 DATA.

K. S. GIGOYAN[1], T. LEBZELTER[2], G. R. KOSTANDYAN[1], ET AL.

[1] Byurakan Astrophysical Observatory, Armenia

[2] University of Vienna, Department of Astrophysics, A1189 Vienna, Austria

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kgigoyan@bao.sci.am

ABSTRACT

In this paper we study bright M–type giants found in the First Byurakan Survey (FBS) low-resolution (lr) spectroscopic data base. Phase dependence 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 second Gaia data release data (Gaia DR2) high-quality photometric data are analyzed to estimate some important physical parameters for 1096 M-type giants found at high Galactic latitudes. Their Gaia DR2 broad-band G magnitudes are in the range 8.0< G <16.0 mag. Gaia DR2 radial velocities (RV) are available for 134 and luminosities for 158 stars out of 1096. The Gaia DR2 color -absolute magnitude diagram (CaMD), their Galactic distribution, also some other diagrams based on Gaia DR2 photometric data are presented. Absolute magnitudes cover the range $+1.0 \geq M(G) \geq -5.4$ mag. They follow to the behaviors and occupy the same regions on the color-magnitude diagrams studied in many papers by different researchers for long period variables (LPVs). Particularly, we consider the locations of the FBS giants on the new diagrams, using

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multi-band approaches in combination with Wesenheit functions, obtained recently by Lebzelter and colleagues (2018) for the oxygen-rich (O-rich) and carbon-rich (C-rich) LPVs in the Large Magellanic Cloud. Period-Luminosity (P-L) diagram was presented for 112 M Mira-variables. The upper limit of the initial stellar masses can be estimate near 4 $M_{\bullet}$ for M giants according to the new diagnostic tools. The kinematic properties, space distribution also more interesting cases among the sample were considered.

Key words. Late-type stars: Astronomical data bases-Surveys.

CHAPTERS

1. INTRODUCTION

The First Byurakan Survey (FBS), known also as the Markarian survey, was the first systematic objective-prism survey of the extragalactic sky. This survey was conducted by B. E. Markarian and collaborators from 1965 to 1980. The photographic plates were obtained at the Byurakan Astrophysical Observatory (BAO) using the 1-m Schmidt telescope, equipped with a 1.5° prism, giving a reciprocal dispersion of 1800 Å/mm near H_γ throughout a useful field of 4° × 4°. FBS is large-area low-resolution (lr) spectral survey, covering a total ~17 000 deg^2. It is segmented into 28 parallel zones on all the northern sky and part of the southern sky at high galactic latitudes with δ >-15° and |b|>15°. The limiting magnitude is 17.5-18.0 mag in the photographic band-pass. Various Kodak emulsions were used during the observations (IIF, IIAF, IIaF, and 103aF), providing a spectral range of 3400-6900 Å (with a 70 Å-wide sensitivity gap at 5300 Å), and a spectral resolution of R = 96 near H_γ.

1. INTRODUCTION

The FBS was originally conducted to search for galaxies with an ultraviolet excess(UVX; Markarian 1967). In total 1515 UVX galaxies(Markarian galaxies) have been discovered, including many AGN and Starburst galaxies, Seyfert galaxies et al. (Markarian et al. 1989). The discovery of UVX galaxies by Markarian and collaborators was the first and important work based on the FBS spectroscopic plates(Markarian et al. 1997). Several other interesting projects based on the FBS were started in 1987(known as a second part of the FBS, Abrahamian & Mickaelian 1996), which resulted in the discovery of new bright quasi-stellar objects (QSOs), Seyferts, white dwarfs (WDs), subdwarfs (sds), planetary nebula nuclei (PNNs), cataclysmic variables (CVs), and other interesting objects.

1. INTRODUCTION

The second part of the FBS also included the selection, cataloguing and study of faint late-type stars (LTSs) at high Galactic latitudes. The large spectral range of the FBS is also suited to identify cool M-type and carbon (C)-stars. C stars can be identified through the presence of the Swan bands of the C_2 molecule. M-type spectra can easily be separated thanks to the titanium oxide(TiO) molecular absorption bands. Since 2007 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 images and spectra are available on the DFBS web[1] portal in Trieste([1] http://ia2.oats.inaf.it) http://ia2.oats(for more details, see also the web site at

ArAS[2],[2] http://www.aras.am/Dfbs/dfbs.html/).

1. INTRODUCTION

All DFBS plates were analyzed with the help of standard image analysis software. 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, 235 M dwarfs, and 1096 M-type giants was generated

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1. INTRODUCTION

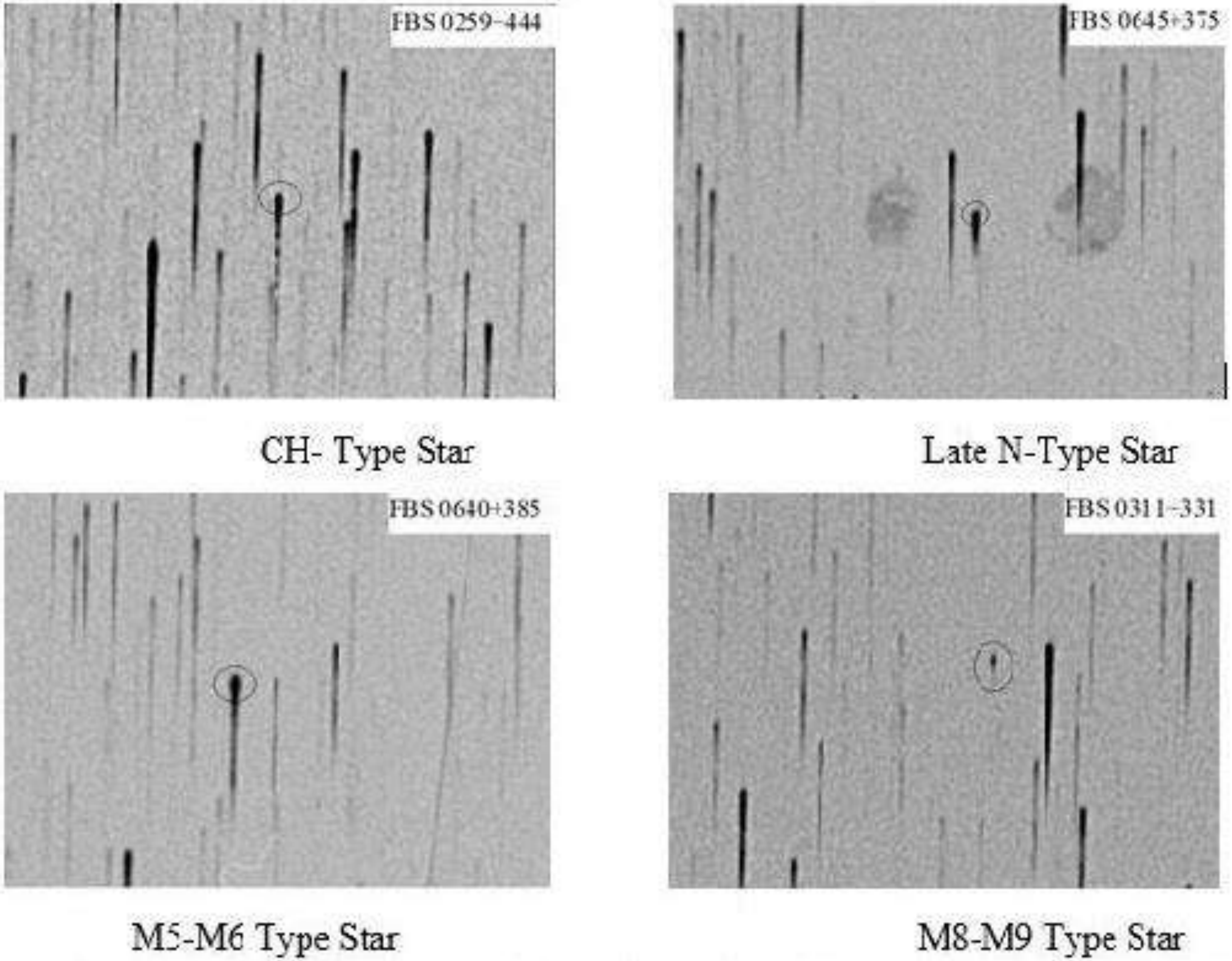

Figure 1 presents the FBS lr spectral shapes for early and late subclasses of the C and M stars.

1. INTRODUCTION

The main goal of this paper is the further exploitation of the Gaia Data Release 2(DR2, Brown et al. 2018) high accurate photometric and astrometric data, also the distance values, presented in Catalogue by Bailer-Jones et al. 2018(Gaia Collaboration), to estimate important physical parameters and to study the distribution of M giants, selected on the FBS plates(Gigoyan et al. 2019), in our Galaxy. A previous paper of this series was devoted to the new C stars discovered on the FBS lr spectroscopic plates (Kostandyan, 2020, Paper IV).

1. INTRODUCTION

Our small paper is structured as follows. In Section 2 we present new additional spectroscopic confirmations for a large number of the FBS selected M giants. In Section 3 we use modern and large sky-area variability data bases to clarify the variability types of the confirmed M giants. In Section 4 we exploit the Gaia DR2 photometric data for these objects to construct color-absolute magnitude diagrams(CaMD) including the Gaia-2MASS-diagram using Wesenheit functions in the Gaia BP and RP and in 2MASS (Skrutskie et al. 2006) J, Ks filters (Lebzelter et al. 2018, A&A V. 616 L13). In Section 5 we focus on the 112 FBS Mira-type variables within our sample. Section 6 summarizes our results.

2. OPTICAL SPECTROSCOPY

- Moderate-resolution CCD spectra were obtained for a large fraction of the FBS LTSs at different epochs and with different telescopes. Optical spectra were obtained with the Byurakan Astrophysical Observatory 2.6-m telescope (BAO, Armenia, spectrographs UAGS, ByuFOSC2 and SCORPIO), with the Observatory de Haute-Provence (OHP, France) 1.93-m telescope (CARELEC spectrograph), with the Cima-Ekar 1.83-m telescope of the Padova Astronomical Observatory (Italy), and with the 1.52-m Cassini telescope of the Bologna Astrophysical Observatory (Italy) as described in Gigoyan et al. (2019). Fig.1 presents the 2.6-m BAO telescope moderate-resolution CCD (EEV 42-40) spectra for two M giants FBS 0135+191 and FBS 1911+487, obtained on November 12, 2018, as illustrative examples. These spectra allowed to confirm the carbon-rich (C-rich) or oxygen-rich (O-rich) nature of our sample stars.

2. OPTICAL SPECTROSCOPY

- Medium-resolution CCD spectra for more than 350 FBS LTSs were secured by LAMOST(Large Sky Area Multi-Object Fiber Spectroscopic Telescope) observations (LAMOST DR5, Luo A -L et al. 2019, 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 % of the FBS M giants.
- Figure 2 presents the LAMOST moderate–resolution CCD spectra for four FBS M giants

2. OPTICAL SPECTROSCOPY

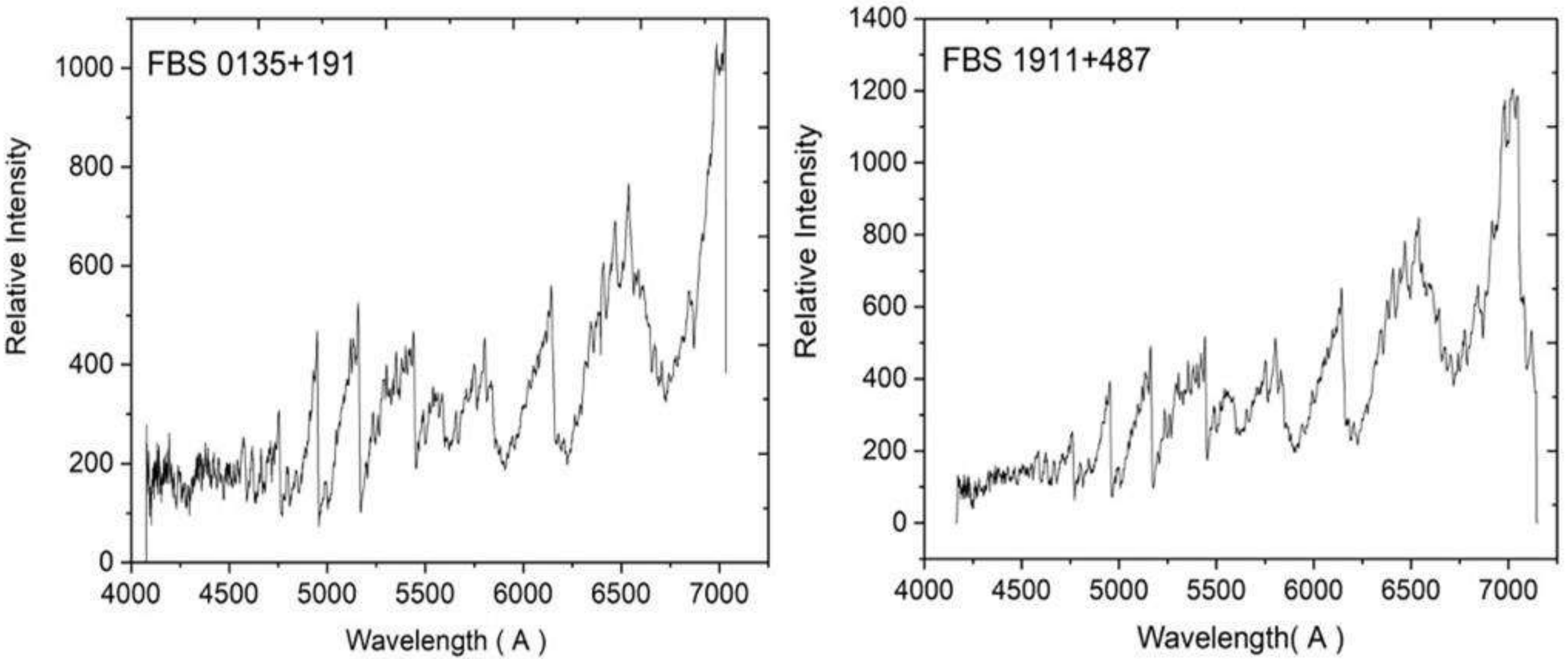

Figure 1. 2.6-m BAO telescope moderate-resolution CCD spectra for two FBS M giants.

2. OPTICAL SPECTROSCOPY

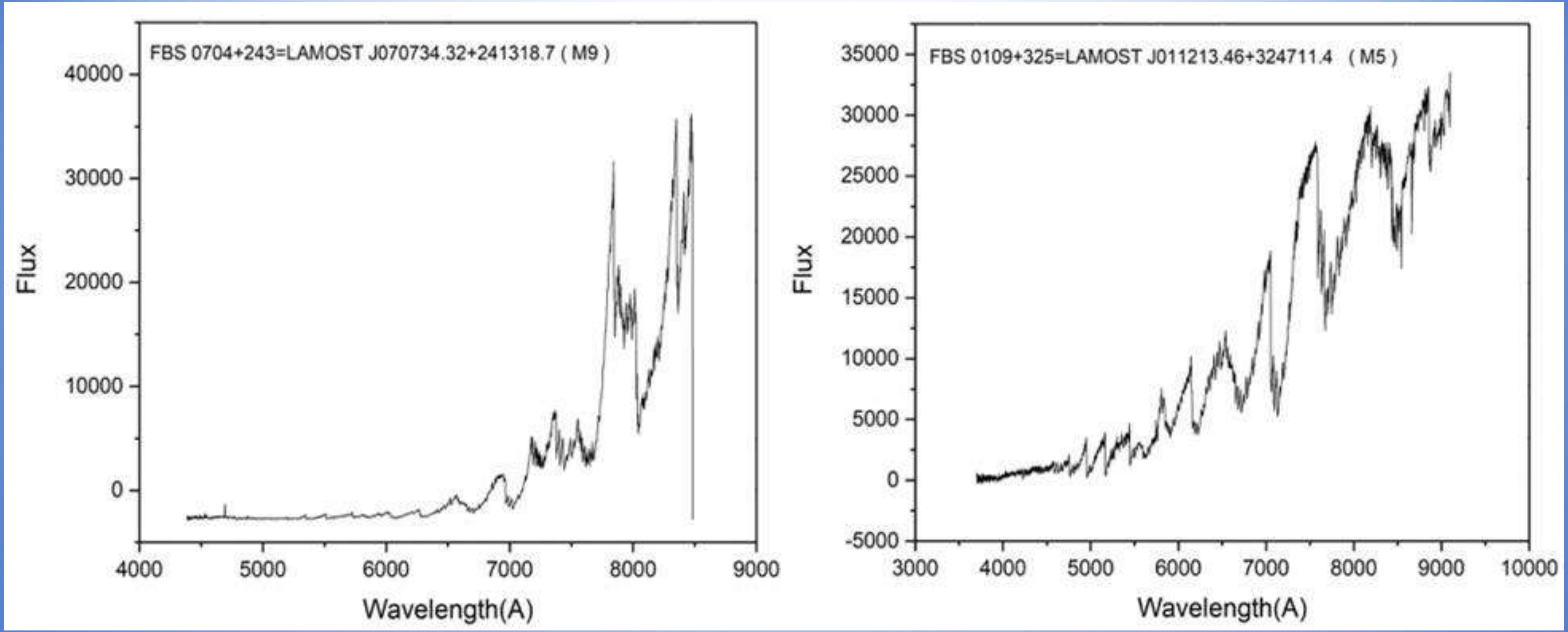

Figure 2. LAMOST moderate-resolution CCD spectra for a sample of FBS M giants

2. OPTICAL SPECTROSCOPY

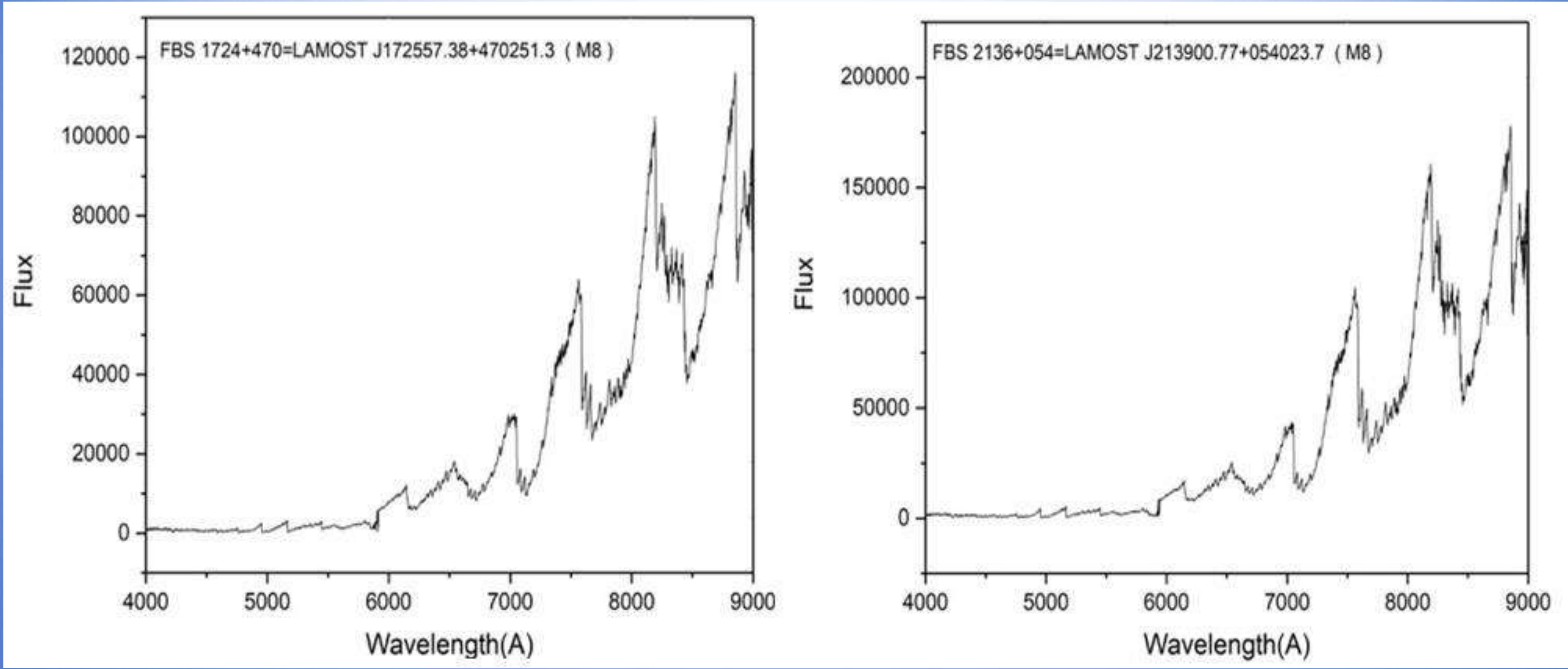

Figure 2. LAMOST moderate-resolution CCD spectra for a sample of FBS M giants

3. VARIABILITY.

To determine the variability of the FBS M type 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.usu.edu/variables (Shappee et al; 2014, Kochanek et al 2017, Jayasinghe et al. 2018).

3. VARIABILITY.

The CSS comprises two main parts surveying the Northern (Drake et al. 2014) and the Southern (Drake et al. 2017) sky, respectively. Both surveys are analyzed by the Catalina Real-Time Transient Survey (CRTS) in search for optical transient ($V < 21.5$ mag.) phenomena. The ASAS-SN project is an all-sky optical monitoring to a photometric depth $V \leq 17$ mag. providing also variability classification. As a consequence, ASAS-SN was used as the primary source for attributing variability types, periods, and amplitudes to the FBS M giants. For the few objects not present in the ASAS-SN data base, variability parameters were determined from CSDR2 light curves using the VStar-data visualization and analysis tool (Benn, 2012). Our final sample consists of 690 Semi-Regular (SR)-type, 294 L-type and 112 Mira-type variables.

3. VARIABILITY.

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Catalina Sky Survey

The Catalina Surveys Data Release 2 (CSDR2)

CRTS

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Welcome to the second data release from the Catalina Surveys Team.

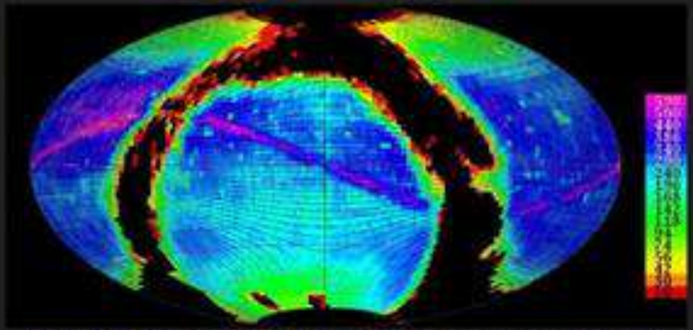
New (2018-06-27): Photometry for all 5540 CRTS-I transients discovered in CSS data.
2017-11-15: Updated Catalina RR Lyrae Catalog (43,389 lightcurves).
2017-05-24: Catalina Southern Periodic Variable Star Catalog.
2014: Catalina Northern Periodic Variable Star Catalog.

Find out what's new about CSDR2.

Introduction

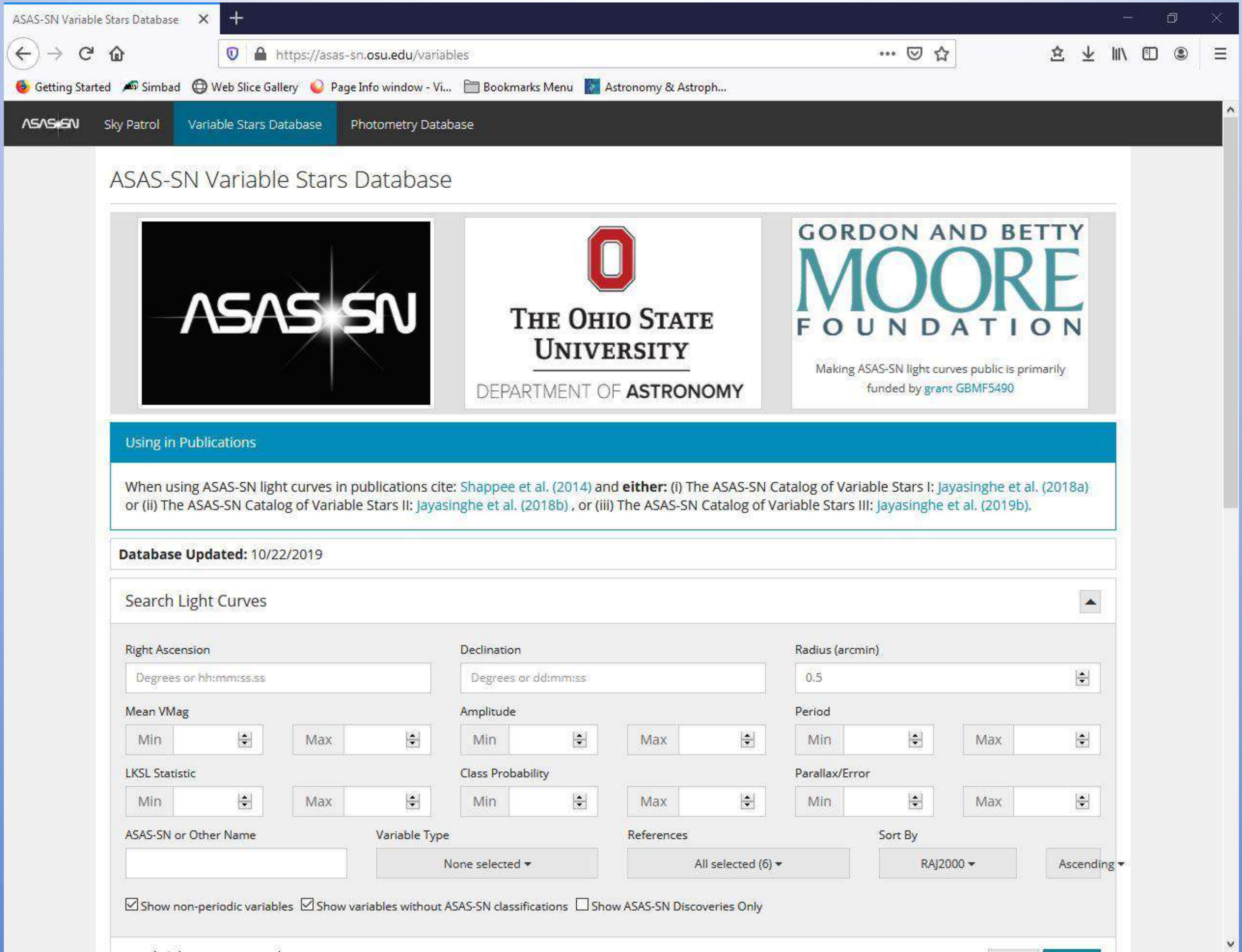
The *Catalina Surveys* consist of the Catalina Sky Survey (CSS) and the Catalina Real-time Transient Survey (CRTS).

The CSS project involves searches for rapidly moving Near Earth Objects (NEOs), while CRTS searches for stationary optical transients (OTs). Both surveys work collaboratively to extract the maximum scientific return from data from three telescopes operated by CSS. In this same collaborative spirit we are now providing an open-access to all the archival photometry.



An Aitoff projection of the sky region covered by this release in equatorial coordinates (centered at RA=0h). The colour key gives the number of epochs at each location (click for larger image).

3. VARIABILITY.



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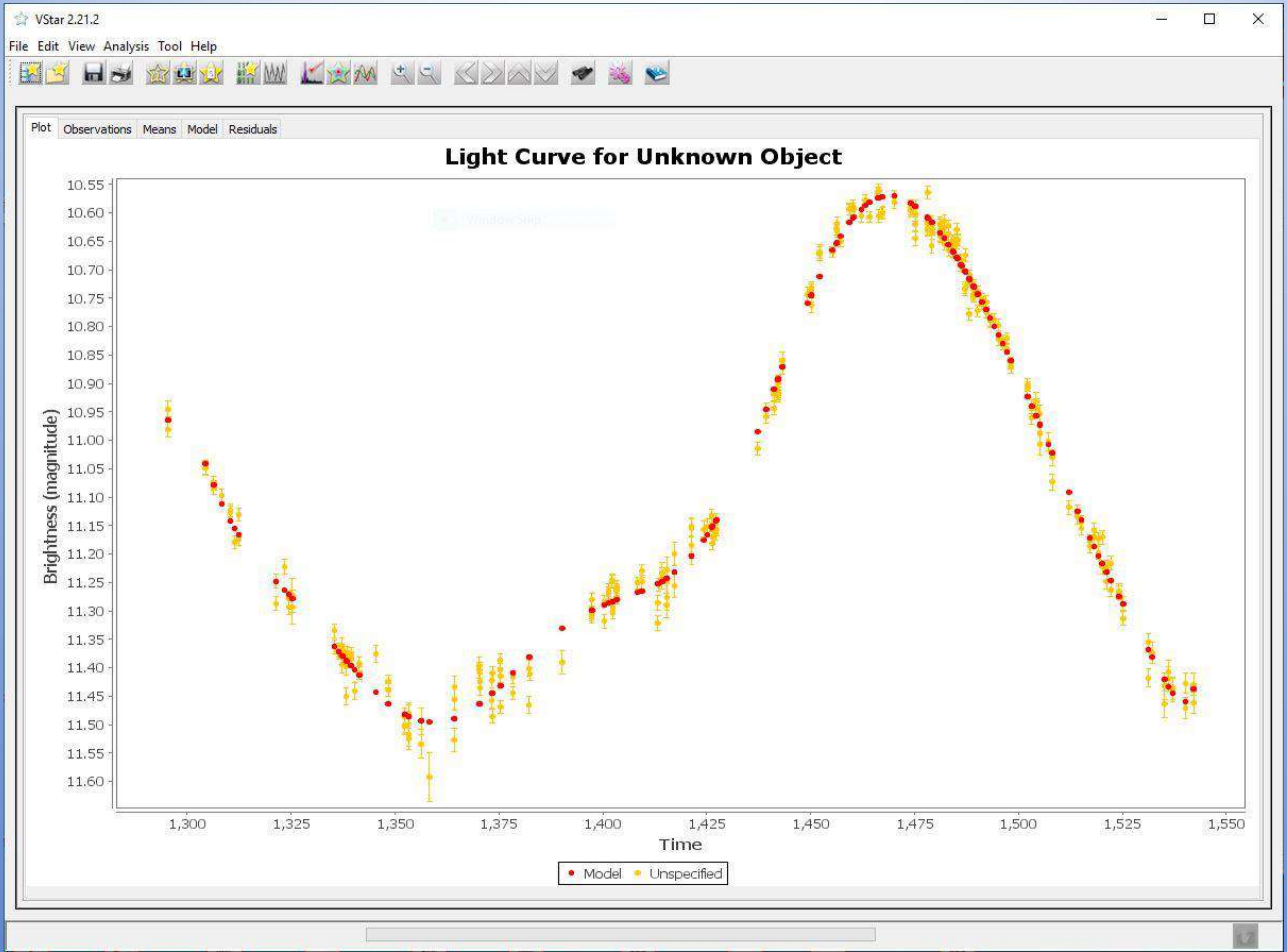
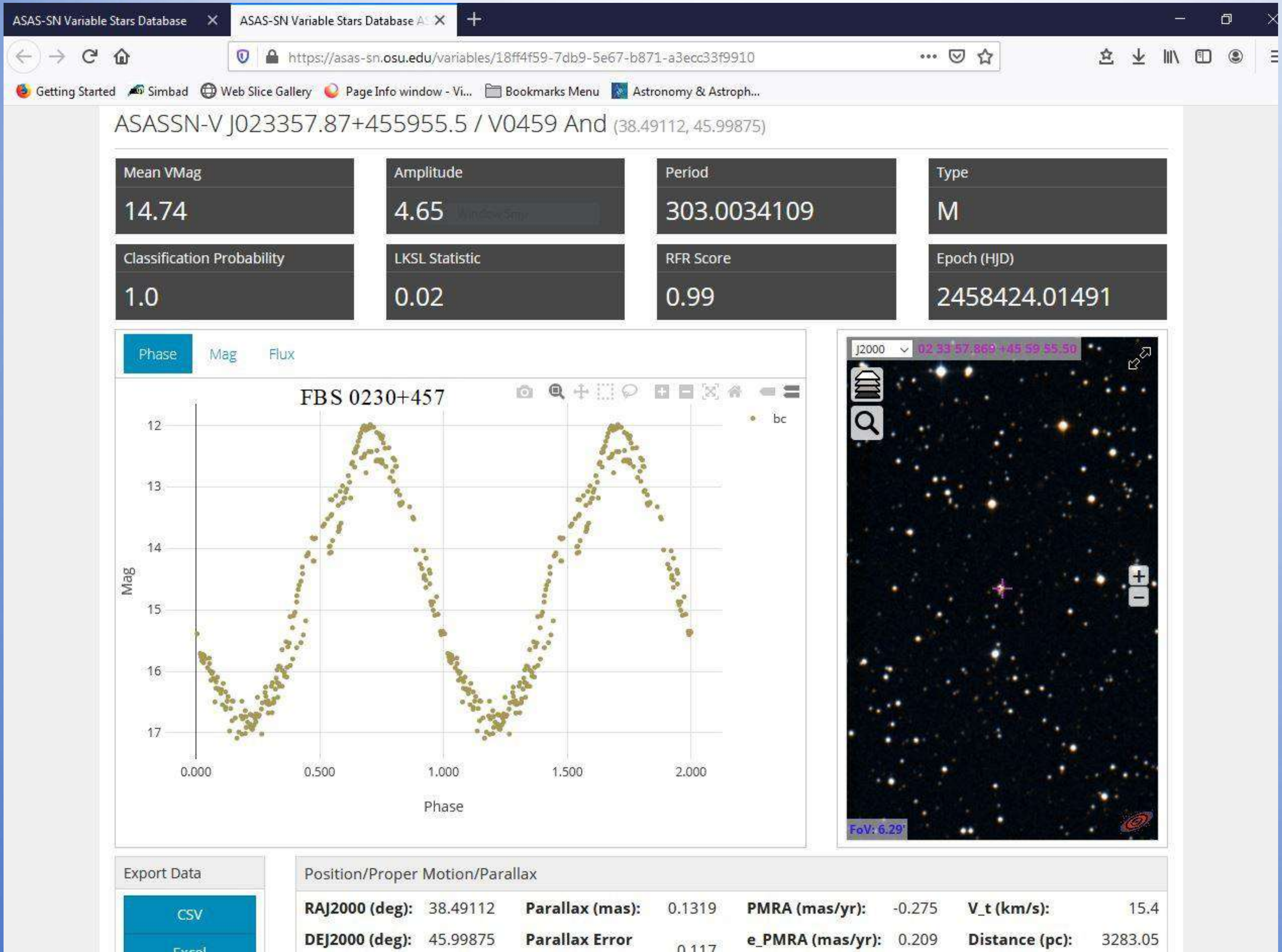


3. VARIABILITY.



4. PARAMETERS DERIVED FROM GAIA DR2

4.1. GAIA DR2 DATA.

With the advent of Gaia mission (Gaia Collaboration, Prusti et al. 2016) a new era in the astronomical research has started. The Gaia DR2 database containing astrometry, three-band photometry, radial velocities, effective temperatures, and information on astrophysical parameter and variability for approximately 1.7 billion sources brighter than G = 21.0 magnitude(Brown et al. 2018). This database opens a new area for investigations based on the Hertzsprung-Russell Diagram (HRD).

4. PARAMETERS DERIVED FROM GAIA DR2

4.1. GAIA DR2 DATA.

All FBS M giants were cross-matched with the Gaia DR2 catalogue sources. The cross-match was carried out using a 5 arcsec aperture around the position of each of our sample stars. They are relatively bright, so that G – band brightnesses were in the range 8.0 mag < G < 16.0 mag.; effective temperatures lay between 3200 K $< T_{eff} <$ 4300 K.

4. PARAMETERS DERIVED FROM GAIA DR2
4.2. COLORS AND LUMINOSITIES

- The radii and luminosities (in Solar units) of 158 M giants of our sample (out of 1096) can be deduced from the Gaia DR2 data base. Luminosities of our target stars range between $L=28.039L_{\bullet}$ (FBS 0255+193 = LAMOST J025756.28+193228.5, M1 star) and $L = 2024.777L_{\bullet}$ (FBS 1306+385=LAMOST J130829.62+381801.4=IRAS 13061+3834, M6 subtype SR-variable). We computed the absolute V-band magnitudes for these objects, adopting that M_V = +4.81 mag for the Sun (see Table 3 in Andrae et al. 2018, for more details), resulting in an absolute V-magnitude range between M_V = +1.1 and M_V = -3.5. A representative sample table with Gaia DR2 data is given as Table 1.

4. PARAMETERS DERIVED FROM GAIA DR2
4.2. COLORS AND LUMINOSITIES

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Gaia Data Release 2

Astronomy & Astrophysics
Special issue

Gaia Data Release 2

First stellar parameters from Apsis

René Andrae[1], Morgan Fouesneau[1], Orlagh Creevey[2], Christophe Ordenovic[2], Nicolas Mary[3], Alexandru Burlacu[4], Laurence Chaoul[5], Anne Jean-Antoine-Piccolo[5], Georges Kordopatis[2], Andreas Korn[6], Yveline Lebreton[7,8], Chantal Panem[5], Bernard Pichon[2], Frédéric Thévenin[2], Gavin Walmsley[5], and Coryn A. L. Bailer-Jones[1]

[1] Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
e-mail: calj@mpia-hd.mpg.de
[2] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Bd de l'Observatoire, CS 34229, 06304 Nice Cedex 4, France
[3] Thales Services, 290 allée du Lac, 31670 Labège, France
[4] Telespazio France, 26 avenue Jean-François Champollion, 31100 Toulouse, France
[5] Centre National d'Etudes Spatiales, 18 avenue Edouard Belin, 31401 Toulouse, France
[6] Division of Astronomy and Space Physics, Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden
[7] LESIA, Observatoire de Paris, PSL Research University, CNRS UMR 8109, Université Pierre et Marie Curie, Université Paris Diderot, 5 place Jules Janssen, 92190 Meudon, France
[8] Institut de Physique de Rennes, Université de Rennes 1, CNRS UMR 6251, 35042 Rennes, France

Table 3. Reference solar parameters.

Quantity	Unit	Value
$\mathcal{R}_\odot$	m	6.957e+08
$T_{\mathrm{eff}\odot}$	K	5.772e+03
$\mathcal{L}_\odot$	W	3.828e+26
$M_{\mathrm{bol}\odot}$	mag	4.74
$BC_{\mathrm{G}\odot}$	mag	+0.06
$V_\odot$	mag	−26.76
$BC_{\mathrm{V}\odot}$	mag	−0.07
$M_{\mathrm{V}\odot}$	mag	4.81

luminosity $\mathcal{L}$ with

$$-2.5\log_{10}\mathcal{L} = M_G + BC_G(T_{\mathrm{eff}}) - M_{\mathrm{bol}\odot}, \quad (4)$$

4. FLAME

The Final Luminosity, Age, and Mass Estimator (FLAME) module aims to infer fundamental parameters of stars. In Gaia DR2 we only activate the components for inferring luminosity and radius. Mass and age will follow in the next data release, once GSP-Phot is able to estimate log g and [Fe=H] from the BP/RP spectra and the precision in T_e and A_G improves. We calculate

4. PARAMETERS DERIVED FROM GAIA DR2 D
4.2. COLORS AND LUMINOSITIES

- Table 1. Gaia DR2 data for a sample of the FBS M giants

FBS Number	Var. Type	G mag.	BP-RP	Luminos.	Other Association
0001+340	L	10.31	3.38	340.28	
0212+858	SR	11.83	2.44	999.79	
0519+021	SR	11.21	3.31	139.47	
1014+819	SR	10.15	2.82	1357.73	IRAS 10147+8159
1306+385	SR	10.06	3.30	2024.77	NSVS 5041274
1757+194	Mira	8.07	2.92	927.80	IRAS 17575+1929

4. PARAMETERS DERIVED FROM GAIA DR2
4.2. COLORS AND LUMINOSITIES

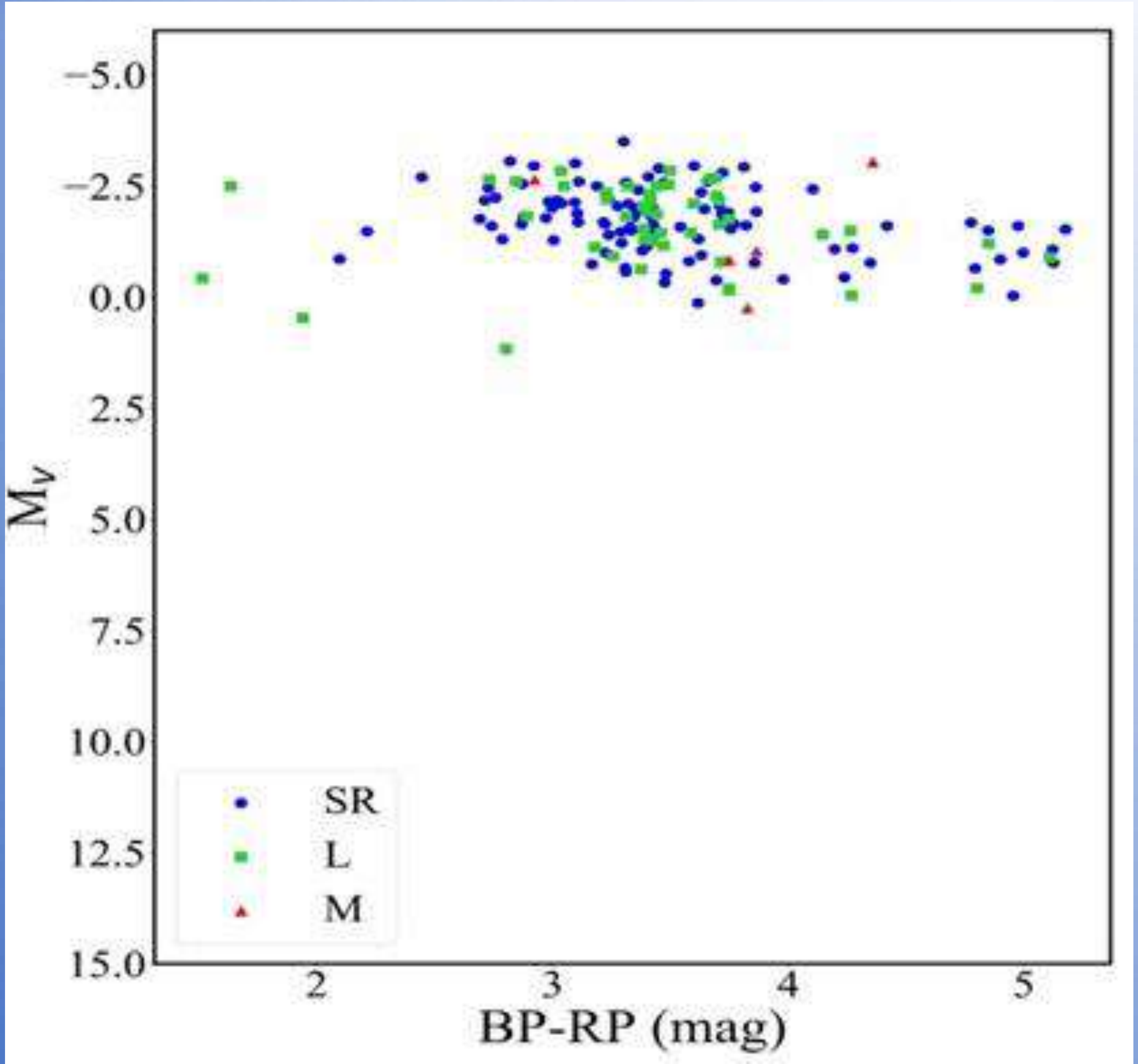


Figure 3. Gaia color-absolute magnitude (M_V vs. BP-RP) diagram of FBS M giants.

4. PARAMETERS DERIVED FROM GAIA DR2

4.2. COLORS AND LUMINOSITIES

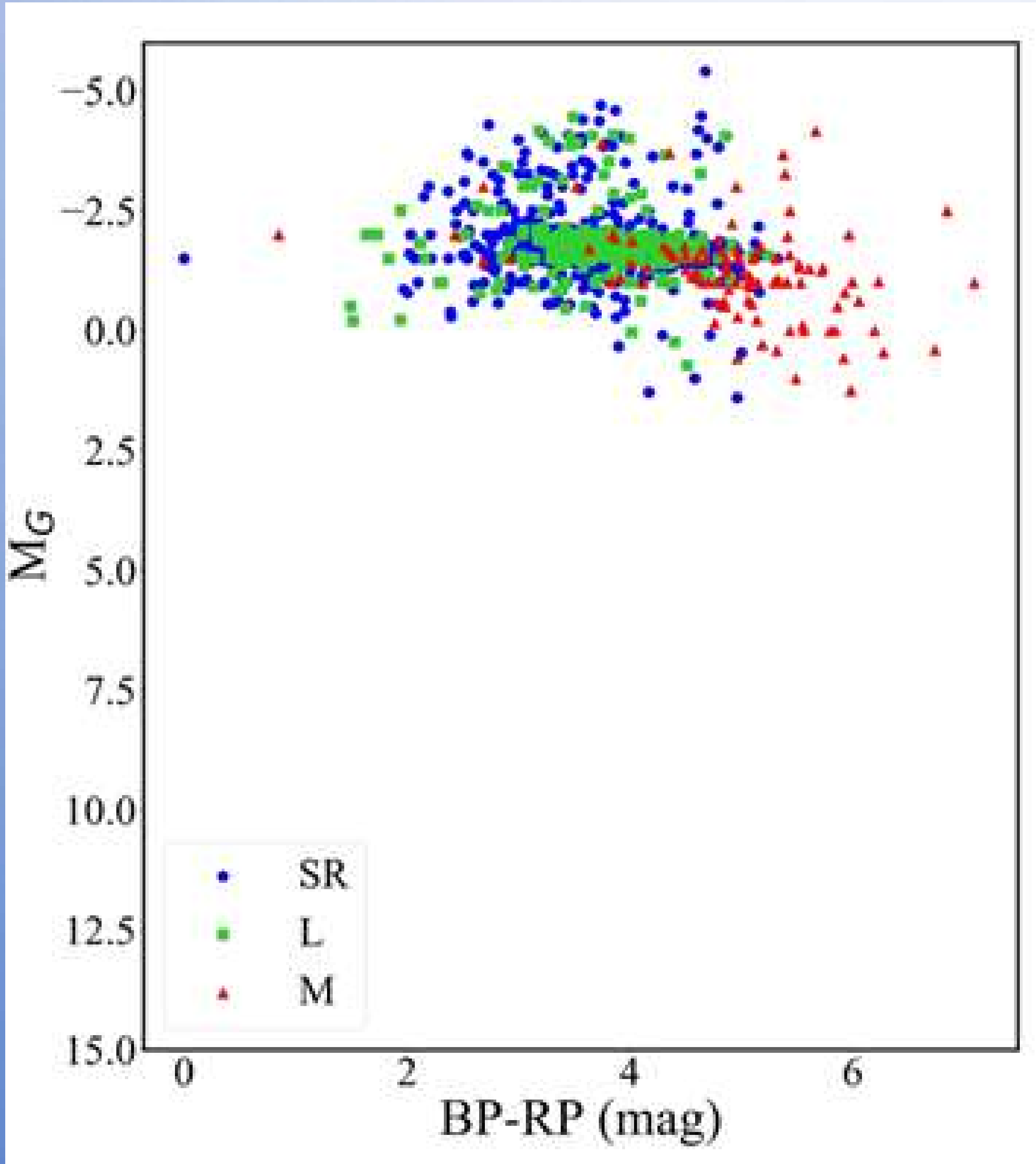


Figure 4. The Gaia DR2 M_G vs. BP-RP color-magnitude for FBS M giants. We use of the distance Information from Gaia DR2 by Bailer-Jones et al. 2018 (Gaia Collaboration, SIMBAD VozieR Catalogue I/347/gaia2dis to plot the CaMD for FBS M giants, We derive absolute G-band magnitude via usual equation:

$$M_G = G - 5 \, \mathrm{Log} \, r + 5 \qquad (1)$$

4. PARAMETERS DERIVED FROM GAIA DR2
4.2. COLORS AND LUMINOSITIES

- The spatial distribution of the FBS M giant stars in Milky Way (Galactic longitude vs. Z, vertical high above/below Galactic plane) of near 1096 FBS M Giants is plotted in Fig. 5. Notice, that the predominant part of objects are found close to Galactic disk, not more than 5 kpc above or below the Galactic plane.

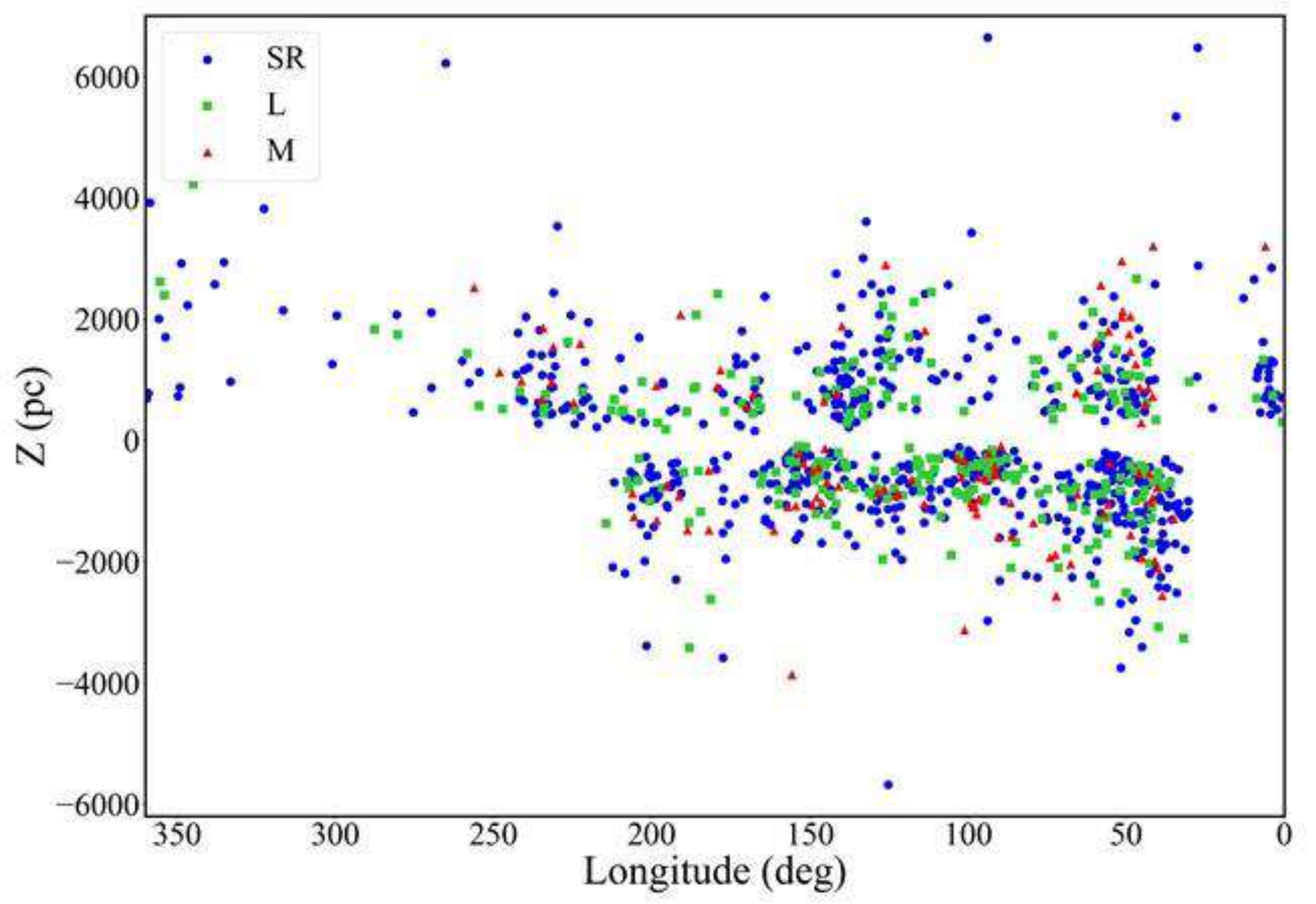


Figure 5. Galactic distribution of the FBS M giants reported in this paper. They predominantly represent the Galactic thin and thick disk populations.

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} – W_{Ks, J-K}$ FUNCTION

- Combining near-infrared and Gaia photometric information, Lebzelter et. al.(2018) constructed a new digram as an analysis tool for red giants. For this, they combined Wesenheit functions in the near infrared and in the Gaia range.

(Wesenheit Index $W_{\lambda1, \lambda2} = m_{\lambda2} - R_{\lambda1, \lambda2}(m_{\lambda1} - m_{\lambda2})$(Madore 1982, ApJ. 253,575)

The 2MASS J and Ks near infrared Wesenheit function is defined as (

Soszynski et al. 2005);

$$W_{Ks, J-Ks} = Ks – 0.686 (J – Ks) \qquad (2)$$

Whereas the Wesenheit function for Gaia BP and RP magnitudes

(Lebzelter et al. 2018) is defined as:

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

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} - W_{Ks, J-K}$ FUNCTION

In Figure 6 we show the application of this diagram for spectroscopically confirmed M and C giants with Gaia distances of our sample ("Second Version Of The FBS LTSs Catalogue "(Gigoyan et al. 2019). Lebzelter et al.(2018) constructed this diagram for Large Magellanic Cloud(LMC) long period variables(LPVs) and demonstrates that it allows to identify subgroups of Asymptotic Giant Branch (AGB) stars sccording to their mass and chemistry. Six distinct groups of red giants with their boundaries had been identified therein (for the definitions of the groups see Table A.1 in Lebzelter et al. 2018). With help of synthetic stellar populations models (based on the TRILEGAL code, Girardi et al. 2005; Marigo et al. 2017) Lebzelter et al.(2018) show that these groups correspond to low-mass, intermediate-mass, and massive O-rich AGB as well as RSG (Red Supergiants) and Extreme C-rich AGB stars, the specific stellar metallicity (see Fig. 3 color coded according to $M_I/M_\bullet$ Lebzelter et al. 2018 for details).

Lebzelter et al., A&A, v616, L13, 2018

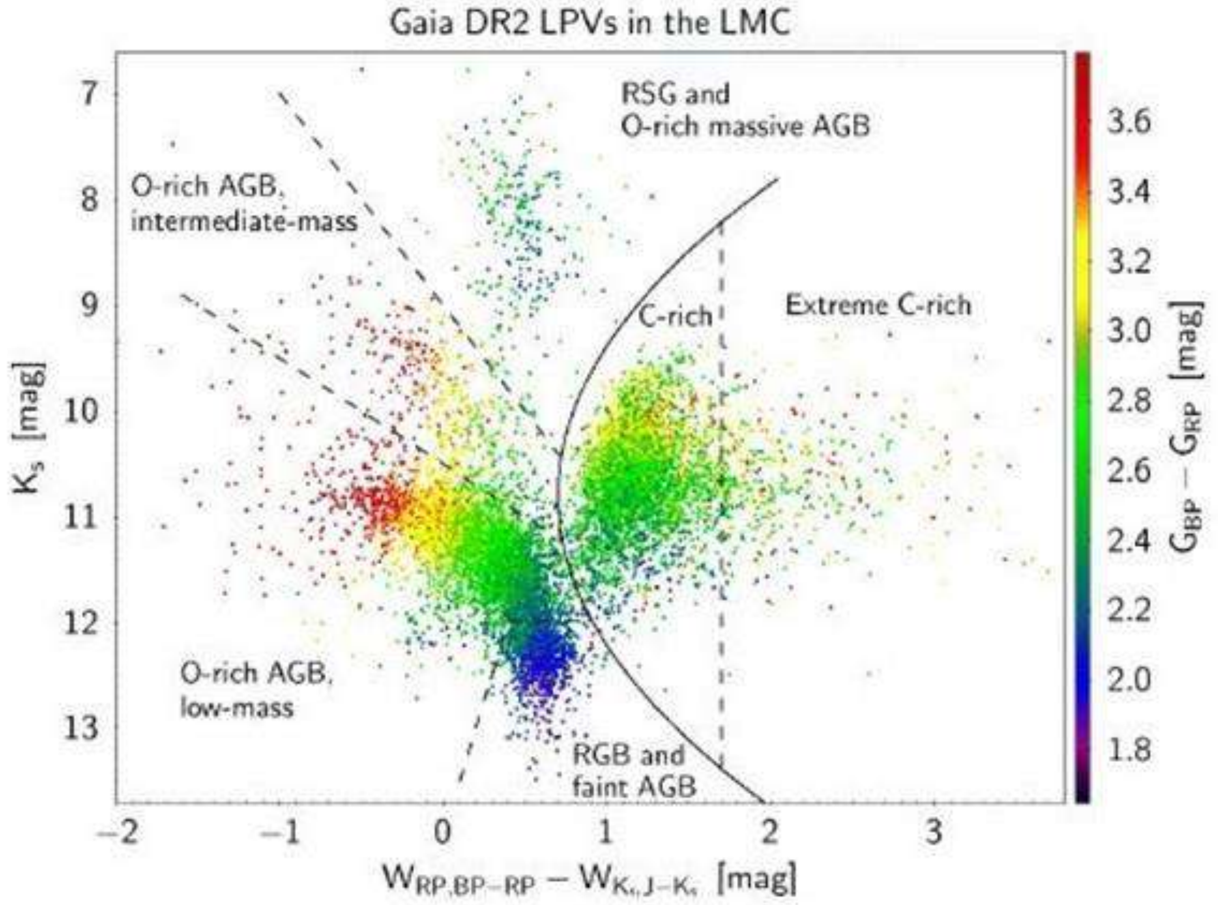


Fig. 1. ($W_{RP,BP-RP} - W_{K_s,J-K_s}$) versus K_s diagram of *Gaia* DR2 LPVs in the LMC. The markers are coloured with $G_{BP} - G_{RP}$ according to the colour-scale shown on the right of the figure. The solid line delineates O-rich (left of the line) and C-rich (right of the line) stars, and dashed lines delineate sub-groups as indicated in the figure. The definition of the borderlines are given in Appendix A.

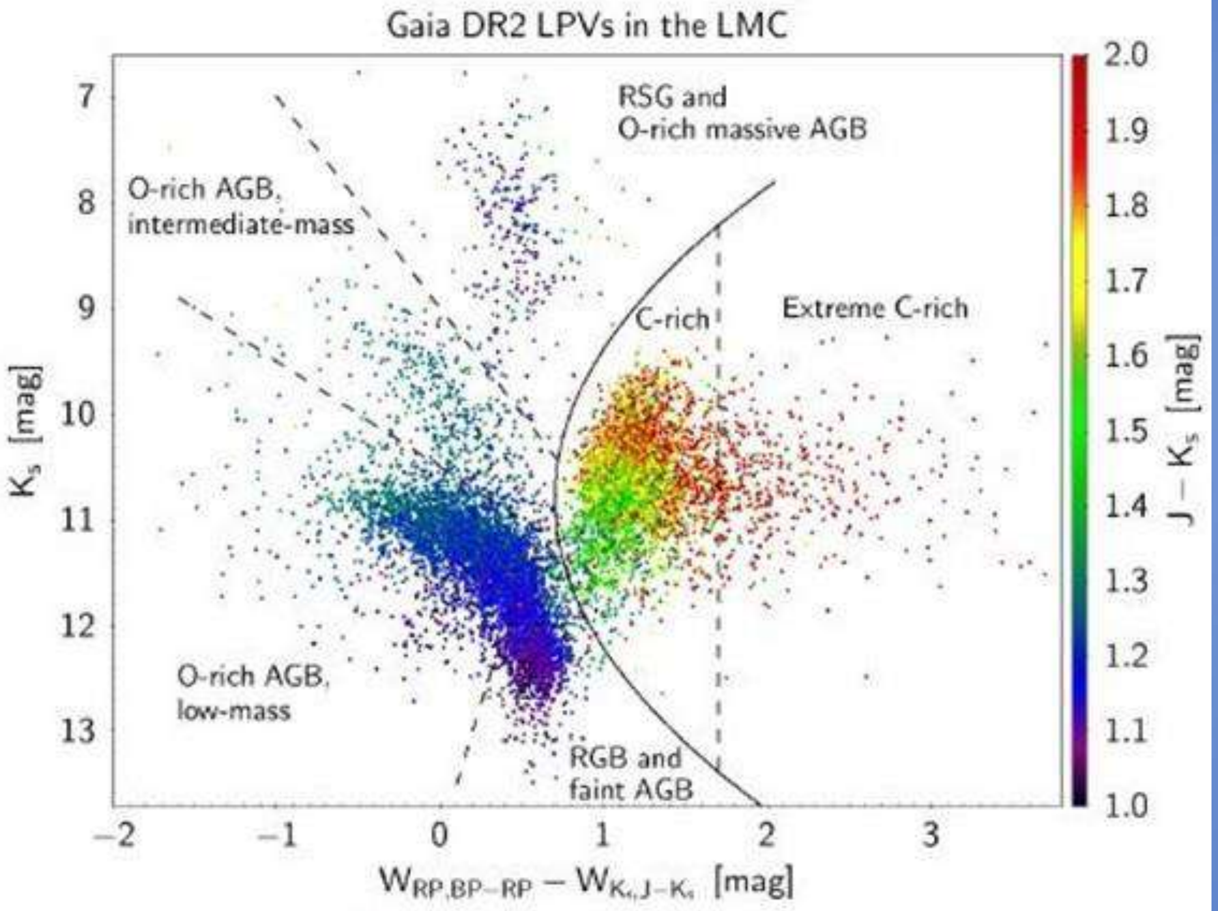


Fig. 2. Same as Fig. 1, but with the markers coloured with $J - K_s$ according to the colour-scale shown on the right of the figure.

In LPVs, W_{RP} combines temperature, chemistry (O- or C-rich), reddening and brightness information. This is not the case for W_K, the colour $J - K_s$ being much less sensitive to the surface temperatures and chemistry of LPVs than $G_{BP} - G_{RP}$ is. We will

Lebzelter et al., A&A, v616, L13, 2018

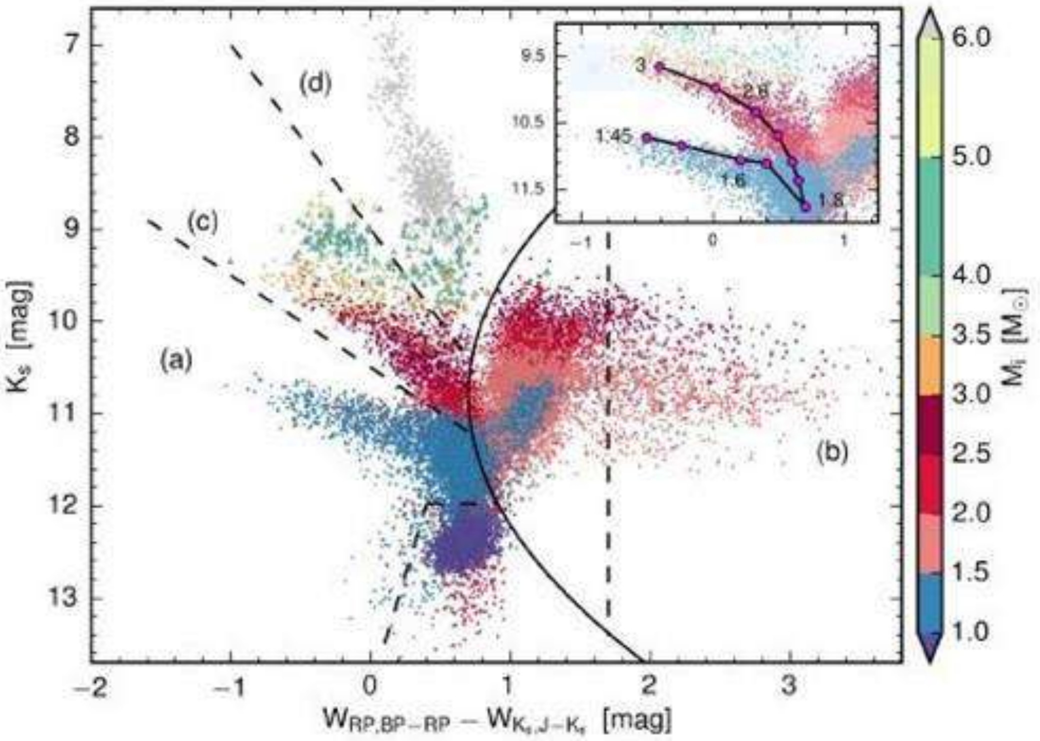


Fig. 3. Synthetic stellar populations for the LMC, colour-coded according to the initial stellar mass. The simulation is obtained with the TRILEGAL code (Girardi et al. 2005) and stellar isochrones that include a detailed description of the AGB phase (Marigo et al. 2013, 2017). Suitable selection criteria for LPVs are applied, based on new pulsation models (Trabucchi et al. 2017). Letters a, b, c, and d identify the main branches of evolved stellar populations. In the inset the curve connects the stages just before stars turn to C-stars at varying initial mass in the range from 1.45 $M_\odot$ to 3 $M_\odot$ (few values in $M_\odot$ are indicated; the initial metallicity is Z=0.006). Triangles are used to mark AGB stars with HBB. See text and Appendix B for more explanation. The dashed and solid lines correspond to the same empirical boundaries as in Fig. 1

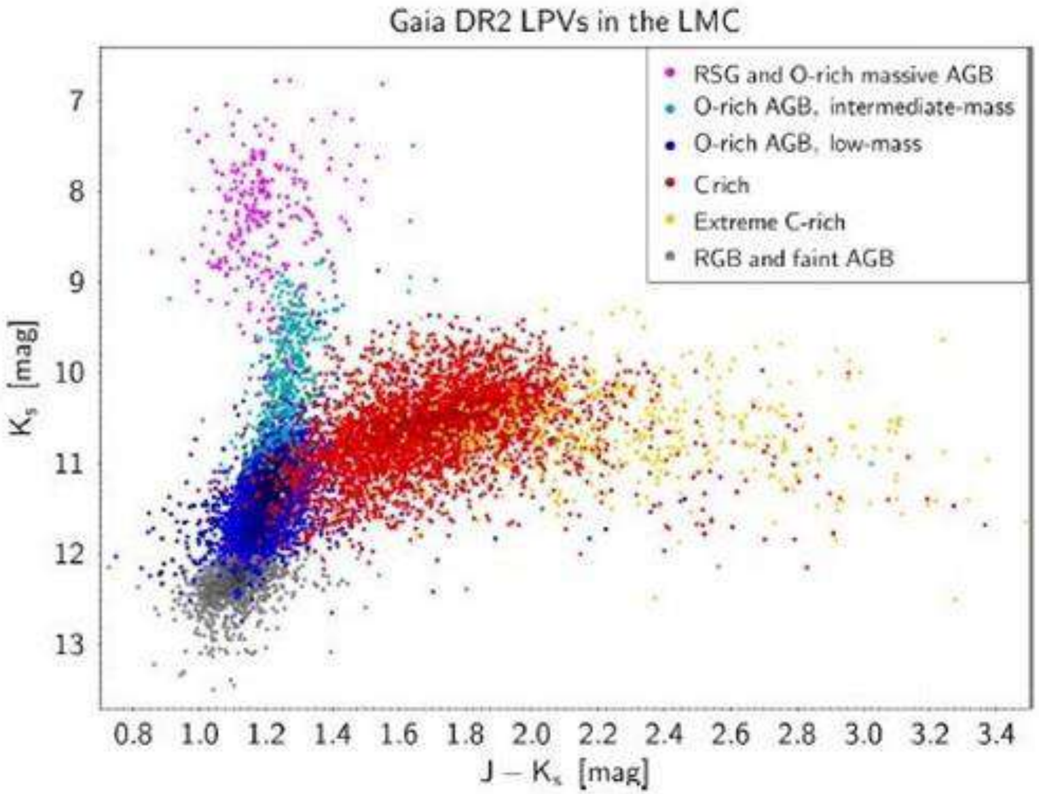


Fig. 4. 2MASS colour-magnitude diagram ($J - K_s$) versus K_s of *Gaia* DR2 LPVs in the LMC. The colour of the symbols are related to the groups of stars identified in Fig. 1 according to the colour-coding written in the inset. The axis ranges have been limited for better visibility.

of the RGB is located close to K_s =12 in the LMC (Cioni et al. 2000). We therefore assume that the stars in the group 'RGB and faint AGB' are primarily tip-RGB stars or stars on the early AGB. For the remaining, brighter, O-rich stars, three subgroups are distinguishable in the diagram, as delineated by the dashed lines on the left of the solid line in the two figures. Comparison

Lebzelter et al., A&A, v616, L13, 2018

- L. Girardi, M. A. T. Groenewegen et al., A&A, V.436p895-915(2005)
- “Star Counts In The Galaxy. Simulating From Very Deep To Very Shallow Photometric Surveys With The TRILEGAL Code”.
- TRILEGAL-TRIdimensional model of thE GALaxy
- The code TRILEGAL was used to model the Galactic Bulge as well as its foreground and background stars. The input to the code is a set of evolutionary tracks, bolometric corrections (which are generated before the code is actually executed, depending on the filter used for observations, and each component of the Galaxy-the thin and thick disk, the halo and bulge), and a set of parameters describing the geometry of this part of the Galaxy.

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} - W_{Ks,\ J-K}$ FUNCTION

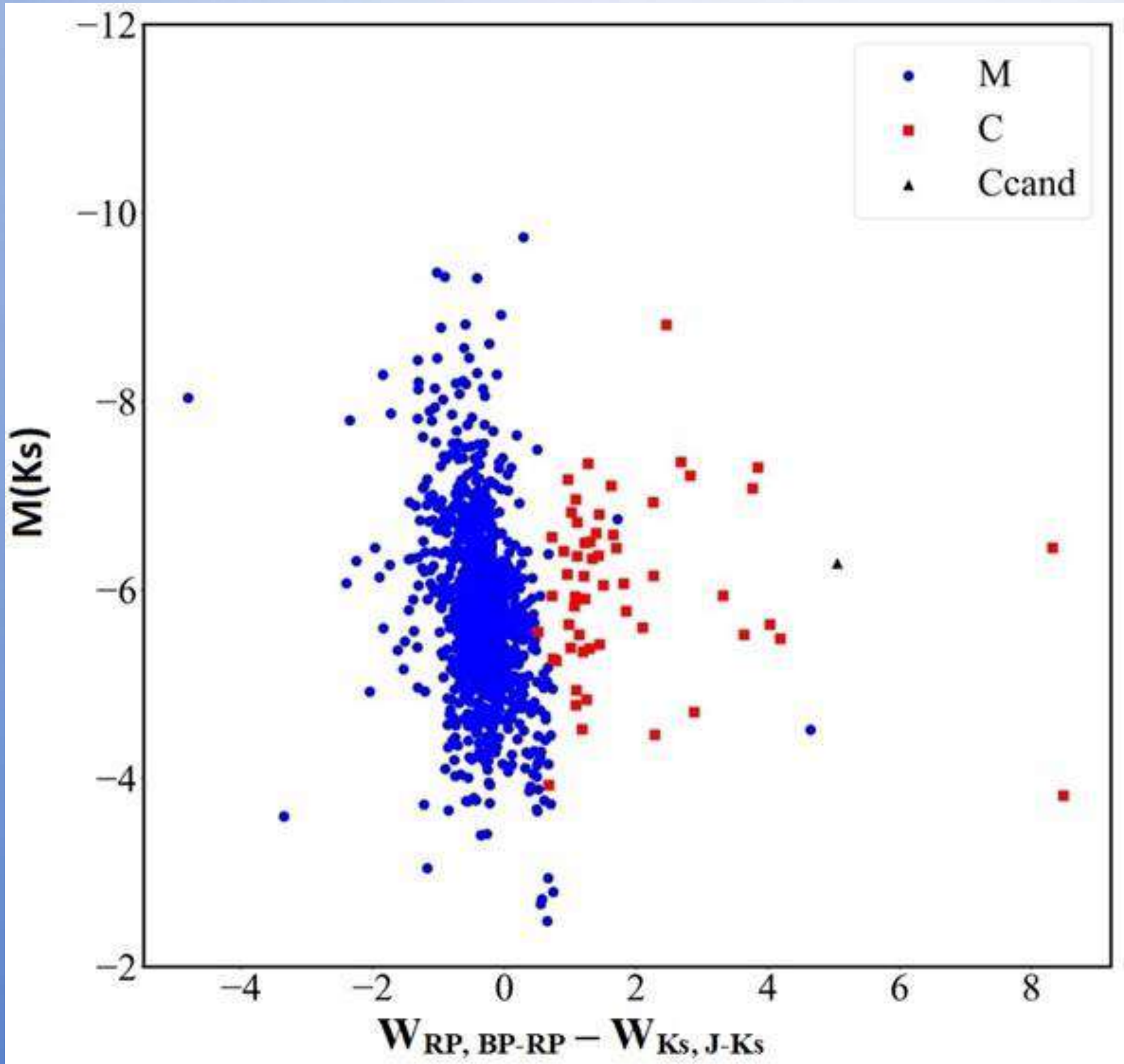


Figure 6. $W_{RP,\ BP-RP} - W_{Ks,\ J-Ks}$ versus 2MASS M(Ks) diagram

for FBS M and C giants. Candidate C star FBS 2216+434 is

noted as a black filled triangle.

4. PARAMETERS DERIVED FROM GAIA DR2
4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} – W_{Ks, J-K}$ FUNCTION

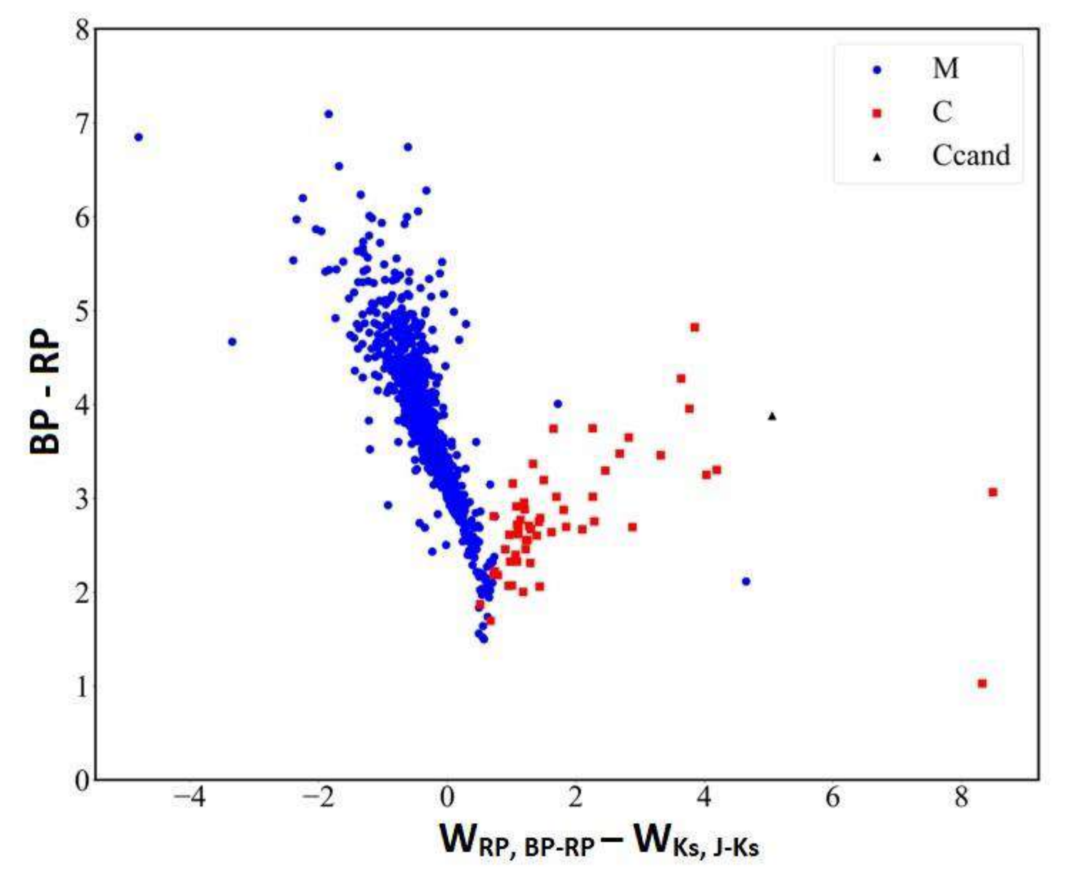


Figure 7. $W_{RP} – W_{Ks}$) versus Gaia DR2 BP-RP color for FBS M and C giants. The point where C and M stars split is around $W_{RP} – W_{Ks}$ ~ 0.8 mag. and BP - RP = 2.3 mag. Objects are getting redder both towards lower and higher values of $W_{RP, BP-RP}$ - $W_{Ks, - J-Ks}$ index. The symbols are the same as in Fig. 5.

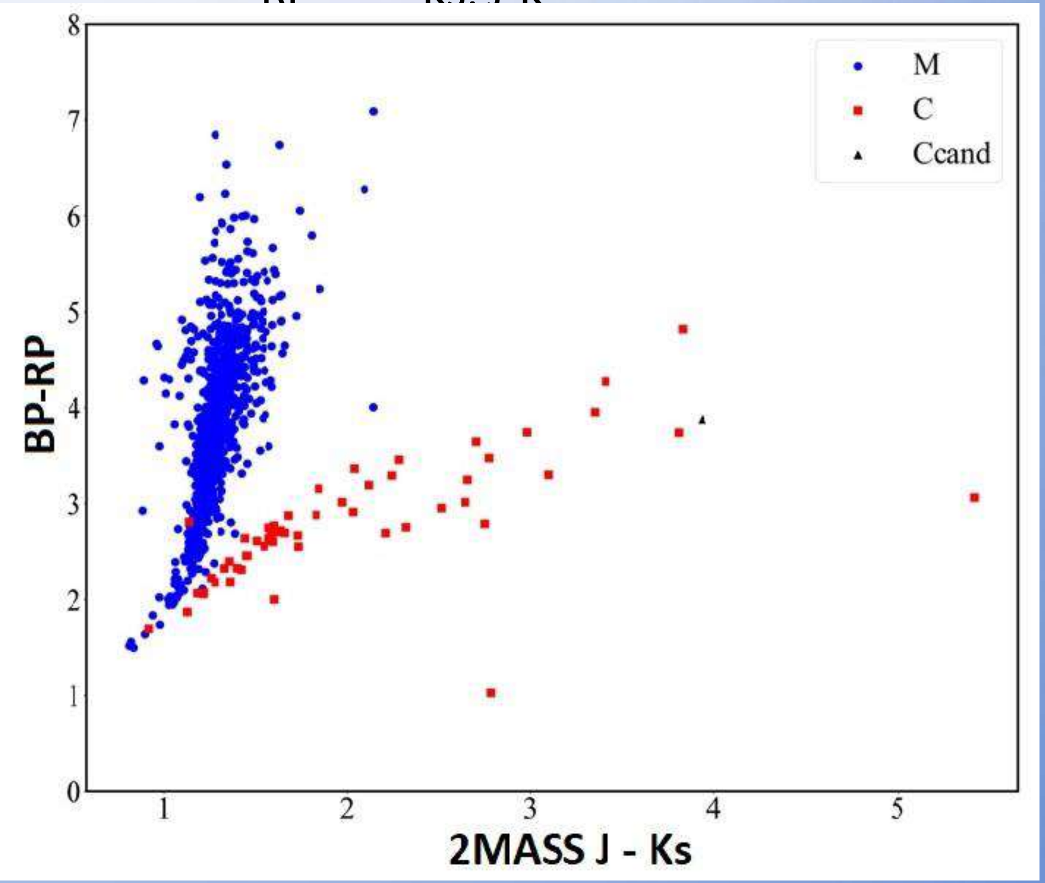


Figure 8. 2MASS J-Ks color versus Gaia DR2 BP-RP color for FBS M and C giants. The point where C and M stars split is around J – Ks = 1.2 mag. and BP-RP = 2.3 mag. The symbols are the same as in Figs. 6 and 7.

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} - W_{Ks, J-K}$ FUNCTION

Fig. 6 nicely confirms the ability of the Gaia-2MASS –diagram to distinguish between M and C-stars, although there are a fe few objects which, according to our low-resolution spectra, show a spectral type different from the one assumed by its lo- cation in that diagram. We will briefly discuss these cases below. In Fig. 7 we present a modified version of this diagram with $G_{BP} - G_{RP}$ on the Y-axis. Figure 8 gives a two–color diagram. Figs. 7 and 8 allow a clear distinction between the two chemistries as well. Fig. 7 is of particular interest since the index on the X-axis is reddening free so that any interstellar reddening affects the Y-axis only. The narrowness of the two branches can be seen as an indicator for low reddening of our stars as we had assumed due to their location outside the Galactic disk.

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} - W_{Ks, J-K}$ FUNCTION

In fig. 9 we added the the borders betweenthe various regions identi- fied by Lebzelter et al.(2018) for their red giant LMC sample and shifted to absolute magnitudes using a distance modulus of 18.45 for the LMC (Elgueta et al. 2016, AJ, v152, p29). The majority of the FBS giants occupied 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 $M < 2M_{sun.}$ Besidies 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.

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE $W_{RP} - W_{Ks, J-K}$ FUNCTION

Two M giants are found on right part of the diagram in an area otherwise populated by C stars ($W_{RP} - W_{Ks, J-Ks} > 0.8$ mag.), namely FBS 0825+626=IRAS 08258+6237, a SR variable with J-K = 2.14, M(G) = -1.0 mag., and FBS 2142-089=IRAS 21427-0858=LAMOST J214522.41-084442.4, SR variable, spectroscopic sub-class M6 with J - Ks = 1.21, M(G) = -1.8 mag.

We do not have a spectral class for object FBS 2216+434=IRAS 22165+ 4326=V0367 Lac (SR variable. P=411.59 days, amp.=1.08 mag.), which we consider as a C star candidate since it is found in the C-star region of the diagram. In Fig. 9 it is marked by a black filled triangle. Two C stars of our sample show extreme colors (extreme C-rich, $W_{RP} - W_{Ks, J-Ks} > 1.7$ mag). One of them is FBS 2213+421=V381 Lac, which is a well-known R CrB star (Rossi et al. 2016), and this gives a hint where the group of R CrB stars are expected to sit in the Gaia-2MASS-diagram. The other one is FBS 0658+400= IRAS 06583+4004, a semi-regular variable with a light amplitude of 1.55 mag. No further information on the nature of this star is available, but its location in the diagram suggests high mass loss.

4. PARAMETERS DERIVED FROM GAIA DR2

4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE W_{RP} _ $W_{Ks, J-K}$ FUNCTION

Two M giants on the left side of Fig. 6 (M stars zone) are well separated from the bulk of the stars. These are FBS 0122+ 461, a SR variable star with an amplitude of 1.69 mag (V-band) and a period of 299.2 days, and FBS 0308+414=GG Per, a M8-M9 subclass Mira variable with a light amplitude of 4.92 mag. and period of 278.99 days. M(G) = -2.5 mag. and Vt = 86.5 km/s. Both objects lie in the region (see Fig. 9 below 0 where low-mass AGB stars are located.

4. PARAMETERS DERIVED FROM GAIA DR2
4.3. OTHER CHARACTERIZATIONS USING 2MASS AND GAIA PHOTOMETRY. APPLICATION OF THE W_{RP} – $W_{Ks, J-K}$ FUNCTION

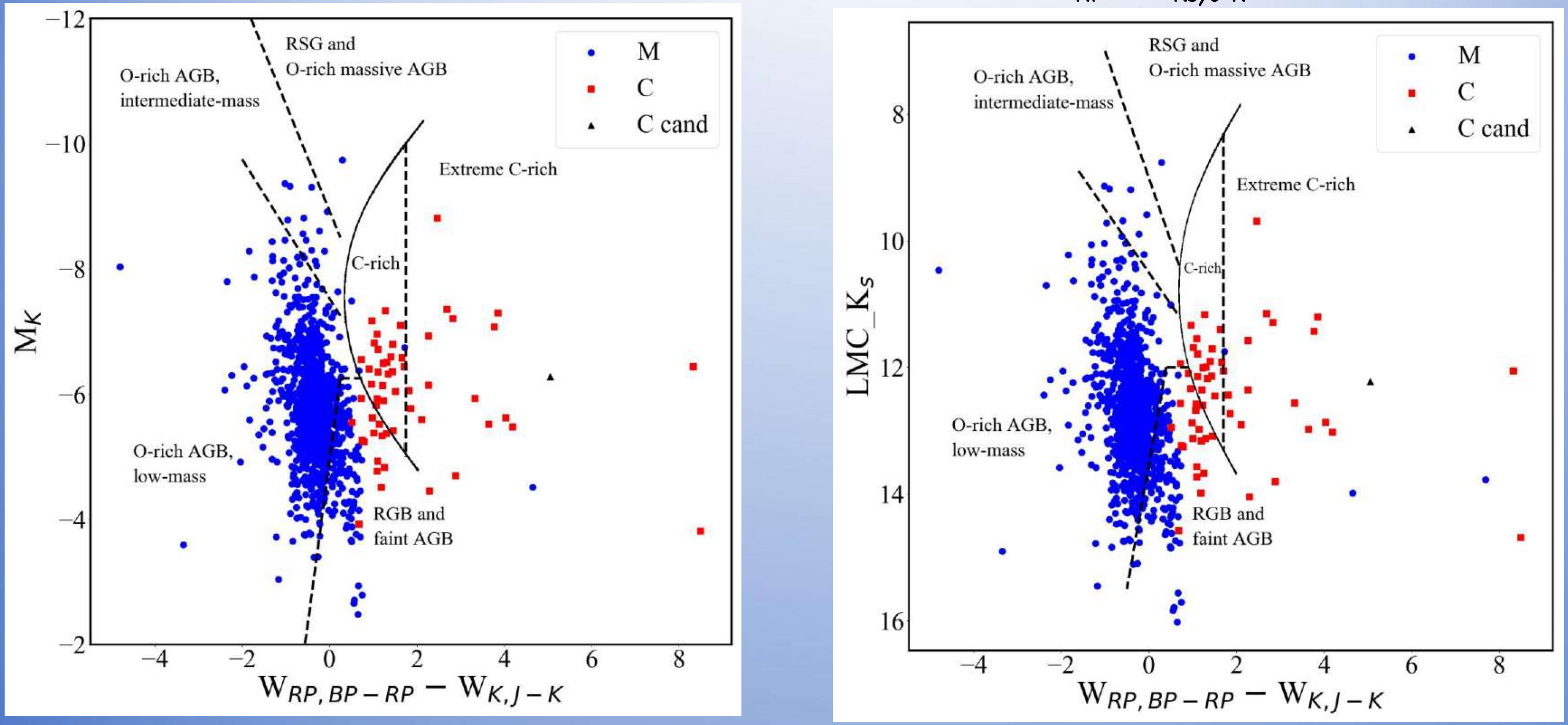


Figure 9. (W_{RP}-$W_{Ks, J-Ks}$ versus M(Ks) for FBS M and C giants. Approximate boundaries of regions (a), (b), (c), and (d) identified for LMC stars in Figs. 1 and 3 by Lebzelter et al. (20180 have been shifted to absolute magnitude values using a distance modulus of 18.45.

4. PARAMETERS DERIVED FROM GAIA DR2

4.4. KINEMATICS

Radial velocity data are available for 134 objects out of 1096. We use here tangential velocities for all FBS objects (available in ASAS-SN database). Tangential velocities are well suited to distinguish various populations within the Milky Way, in particular the Galactic thin disk, thick disk and halo populat- ions because they show different kinematics(Babusiaux et al. 2018 , A&A, Vol 616 A10(Gaia Collabora- tion). Fig. 10 illustrates the tangential velocities (V_t) versus height above / below the Galactic plane for these FBS M giants. Only for 11 objects V_t > 200 km/s was found. The object with the largest tangential velocity (V_t =461.1 km/s is FBS 2053-015, a SR variable 2970 pc away from the Galactic plane.

4. PARAMETERS DERIVED FROM GAIA DR2

4.4. KINEMATICS

Babusiaux et al. (2018) distinguish, based on HRD and kinematics from Gaia DR2 data, thin disk (Vt < 40 km/s), thick disk (60 < Vt < 150 km/s), and halo (Vt > 200 km/s) objects (Figs. 20 and 21 of Babusiaux et al. 2018). Adopting these criteria, the predominant part of the FBS M giants belong to the Milky Way thin and thick disk populations. Among the 11objects we would attribute to the halo population according to their Vt value, there is FBS 1803+224 (Vt = 303.5 km/s), which is a Mira variable with amplitude $\Delta V = 4.1$ mag and P=328.16 days. Its height is estimated to Z = 1465 pc from the Galactic plane.

4. PARAMETERS DERIVED FROM GAIA DR2

4.4. KINEMATICS

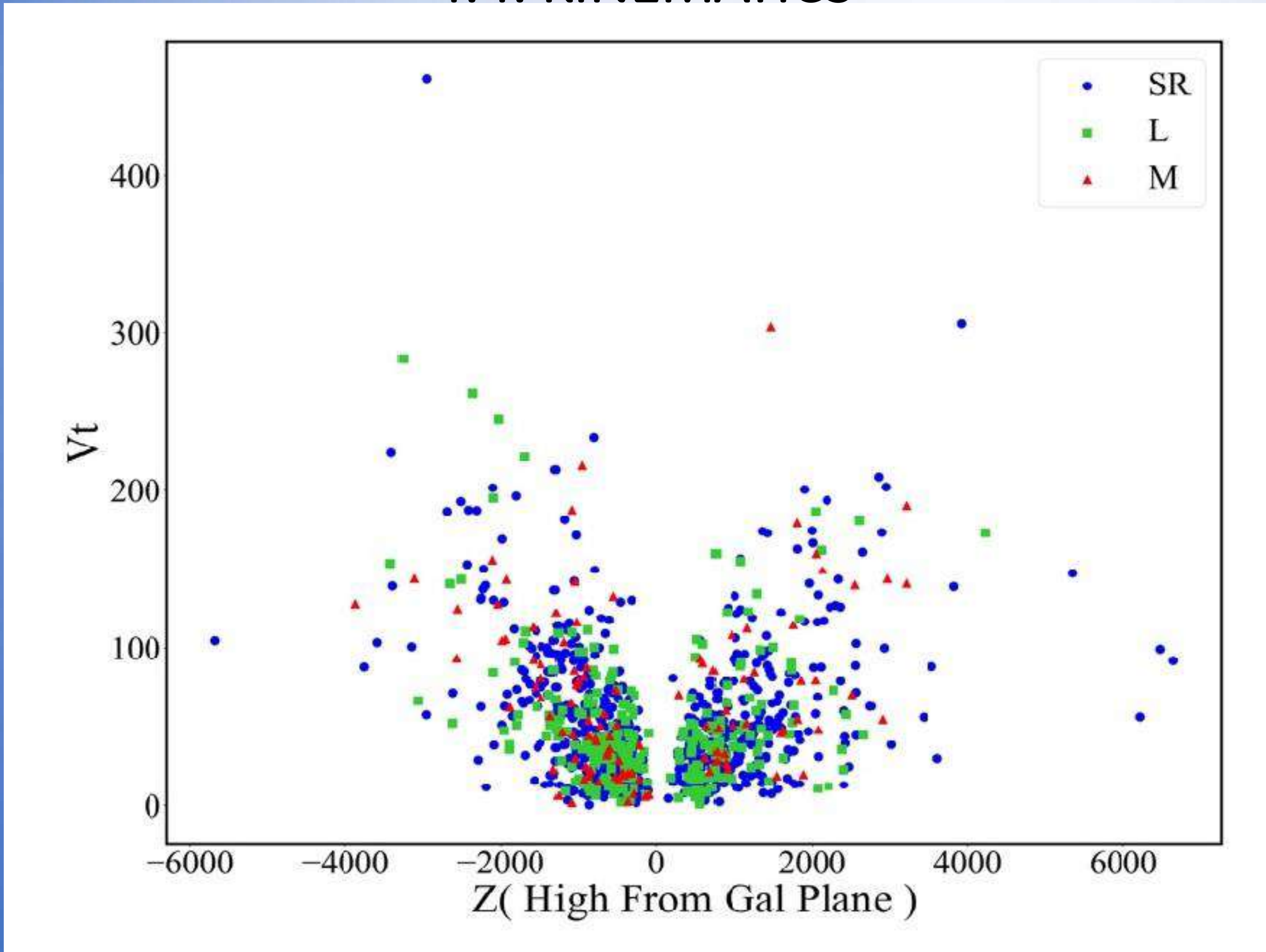


Figure 10. Vt velocity versus height above/below the Galactic plane. The symbols are the same as in Fig. 3 to 5.

5. Mira Variables

Among the 1096 FBS M giants, 112 are classified as Mira variables in ASAS-SN database, all of them being spectroscopically confirmed M – stars. In Figure 11 we present the period versus absolute 2MASS Ks diagram (Period-Luminosity Diagram; PLD) for all FBS M giants with good Gaia parallaxes. The Ks values are not corrected for extinction assuming it to be negligible at high latitudes. The plane of the diagram is divided into three regions according to the areas associated with the P-L sequences C, C' , and D. Almost all the Miras of our sample are found at sequence C (first overtone) and D(long secondary period) are heavily scattered. Four Mira variables with P > 600 days, are located in branch D. Two of them FBS 1423+727 and FBS 2240+107, do not have BP-RP colours in Gaia DR2, likely due to the star being very red. The other two Miras, namely FBS 0309-120, P=651.96 days, amp.=5.96 mag., and FBS 2157+329= IRAS 21576+3259=WX Peg, P=632.34 days, amp.=3.23 mag., belongs to group (c)(intermediate-mass O-rich AGB stars) and to group (a) (low- mass O-rich AGB stars) consequently. The latter one, WX Peg is an OH/IR star (Lewis, 1997, Chi-Young et al. 2017) with a high mass loss rate observable as a mid-infrared excess in its spectral energy distribution((SED, Fig. 12) We assume that the offset of these four objects is due to circumstellar absorption affecting the K brightness.

5. Mira Variables

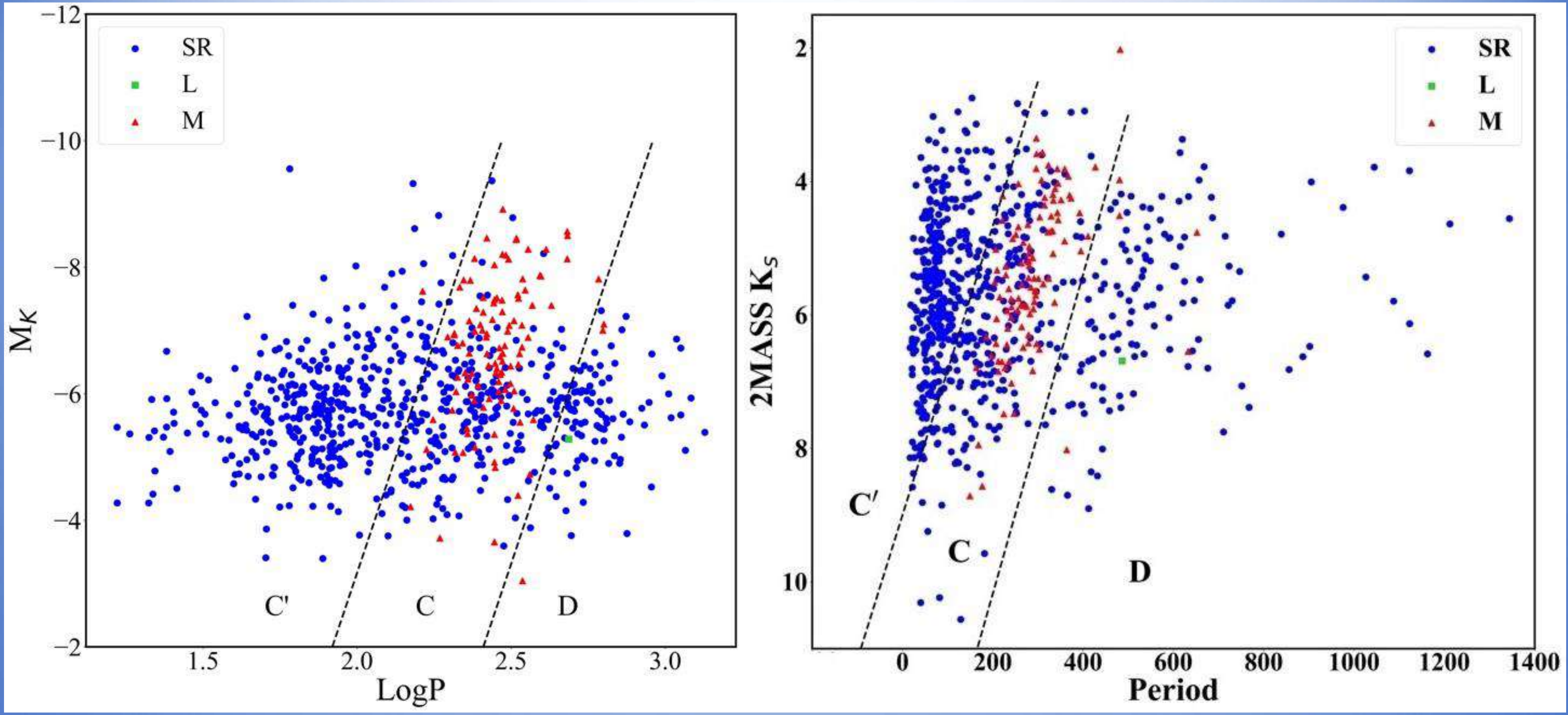
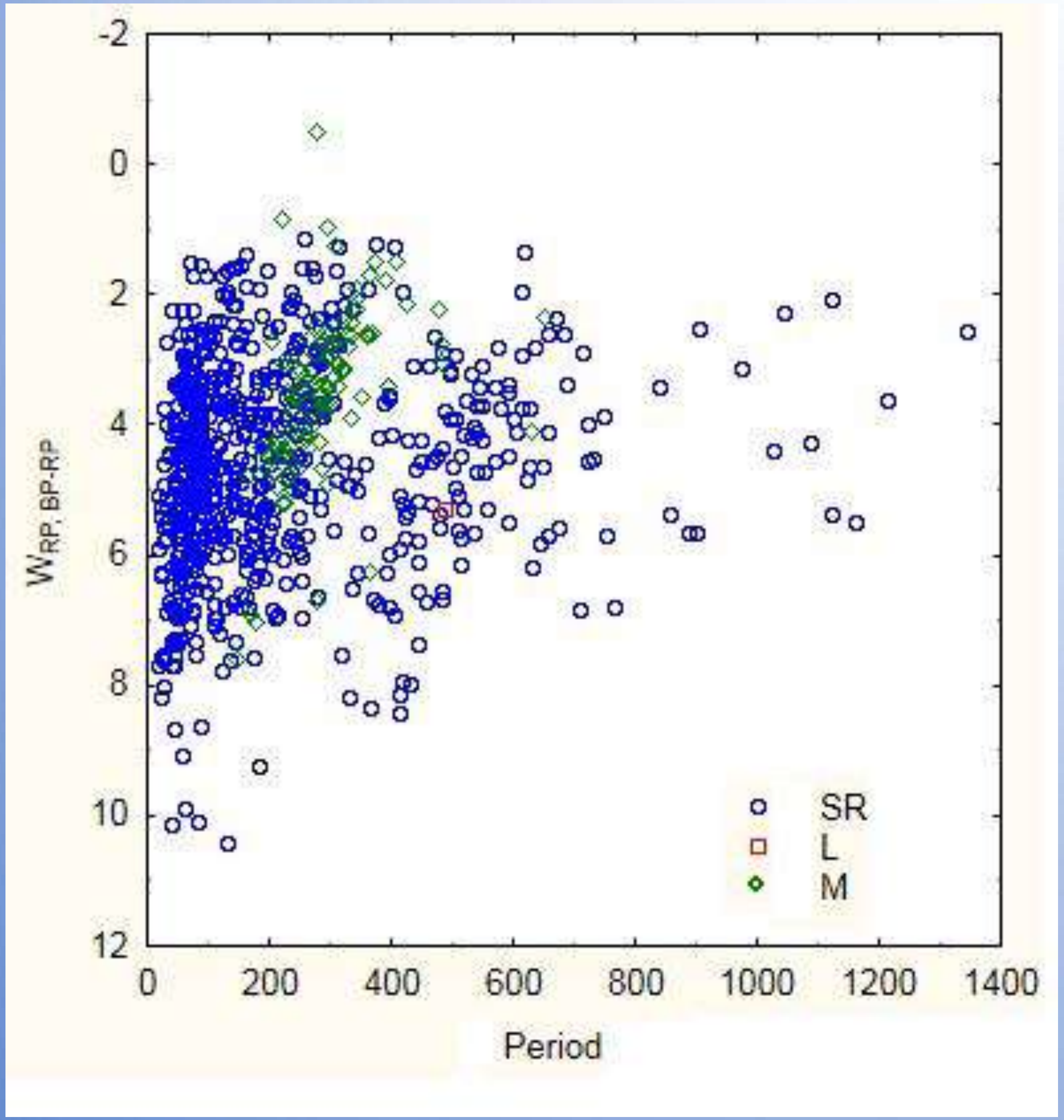


Figure 11. Period-Luminosity diagram for FBS M giants. Dotted lines approximately discriminate the three branches, C' , C, and D (e. g. Lebzelter et al. 2019).

5. Mira Variables



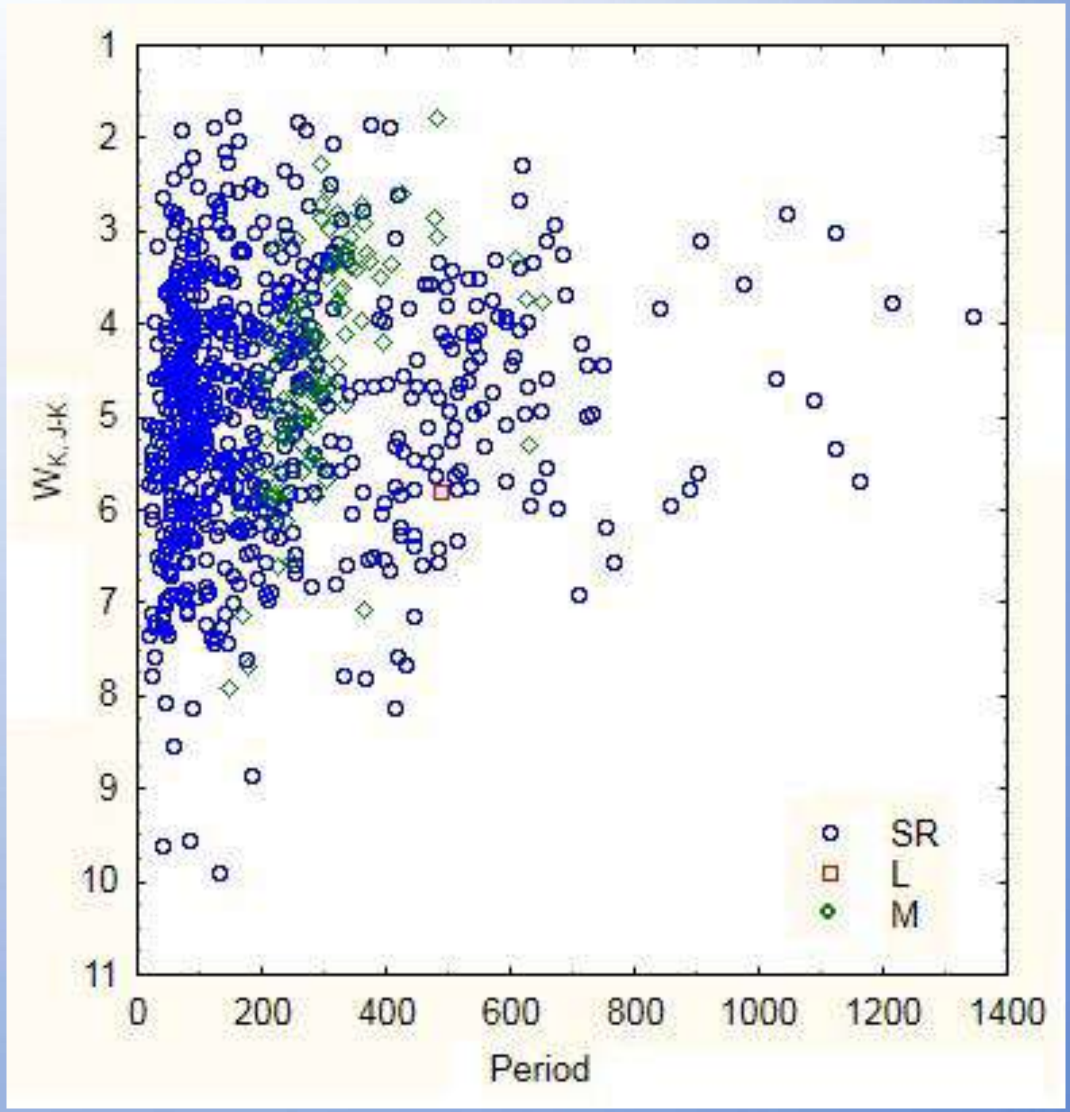


Figure 11. Period-Luminosity diagram for FBS M giants. Dotted lines approximately discriminate the three branches, C' , C, and D (e. g. Lebzelter et al. 2019).

5. Mira Variables

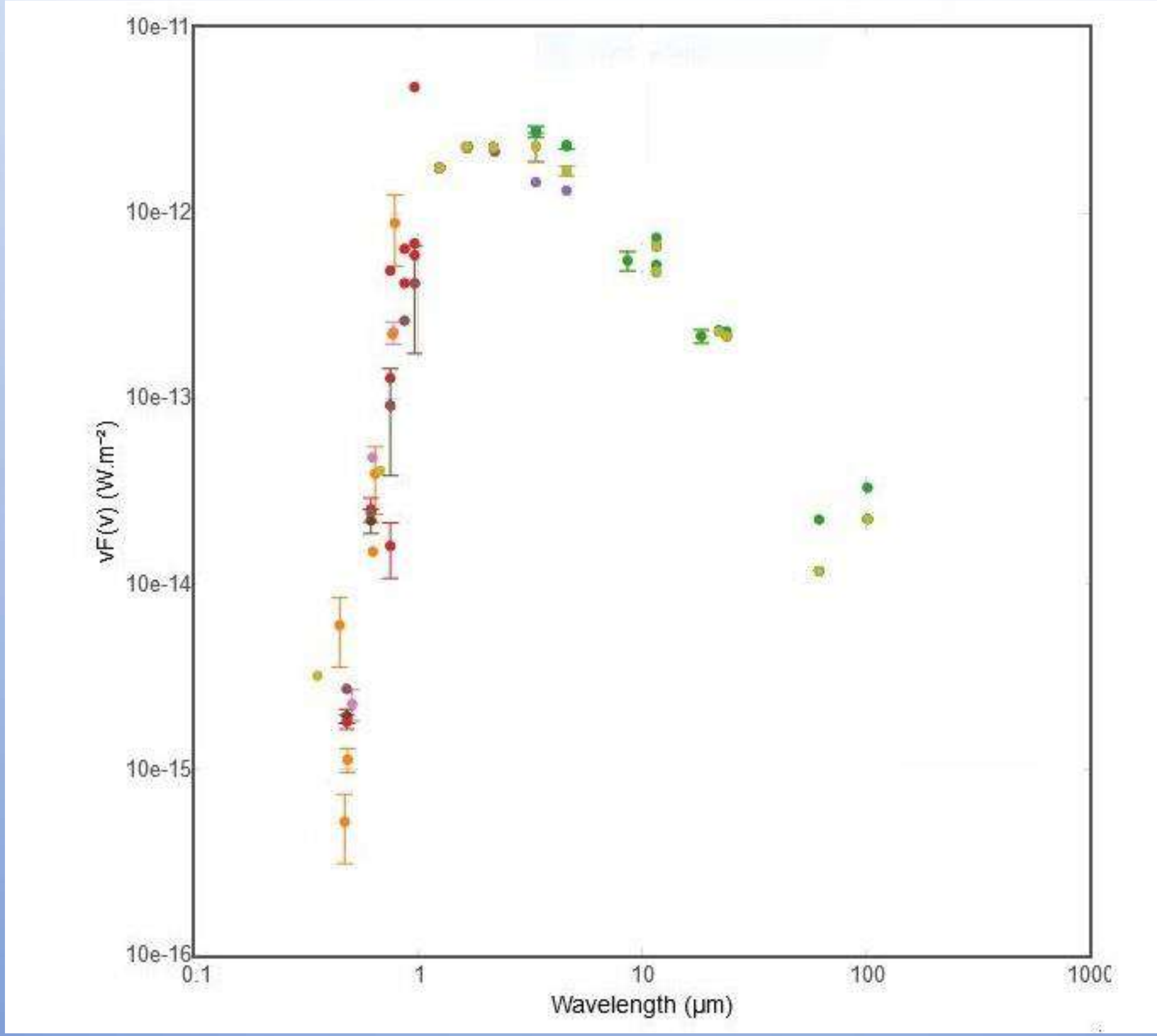


Figure 12. Observational SED of the Mira type variable FBS 2157+329 showing excess near at 10 μm (SED created using https://tools.ssd.asi.it/SED/).

5. Mira Variables

Mira variables are AGB stars that show high amplitude (amp. ≥ 2.5 mag. in the V-band) variability with typical periods 100-1000 days. Both, oxygen-rich and carbon-rich Miras obey distinguished P-L relations (Feast et al. 1989) useable for independent distance calibration (Whitelock et al. 2008). Given that the period of O-type Miras correlates with age, Grady et al. (2019; 2020) used these variables to study age gradients throughout the Milky Way Galaxy, to study the transition in ages between disc and Halo O-rich Miras and compare the relative ages of different Galactic populations as a function of Galactocentric distance. They assembled the largest sample of M-type Miras so far, using data from the Catalina Surveys (Northern and Southern) and the ASAS-SN (~ 2400 O-rich Miras). The period of a Mira increases with increasing luminosity, and hence mass. Thus, longer period Miras correspond to younger ages. Miras of LogP ~ 3.0 have initial masses near 4.0 $M_\bullet$ (Feast, 2008).

Figure 13 presents histogram of the ASAS-SN period for 112 FBS M Miras.

5. Mira Variables

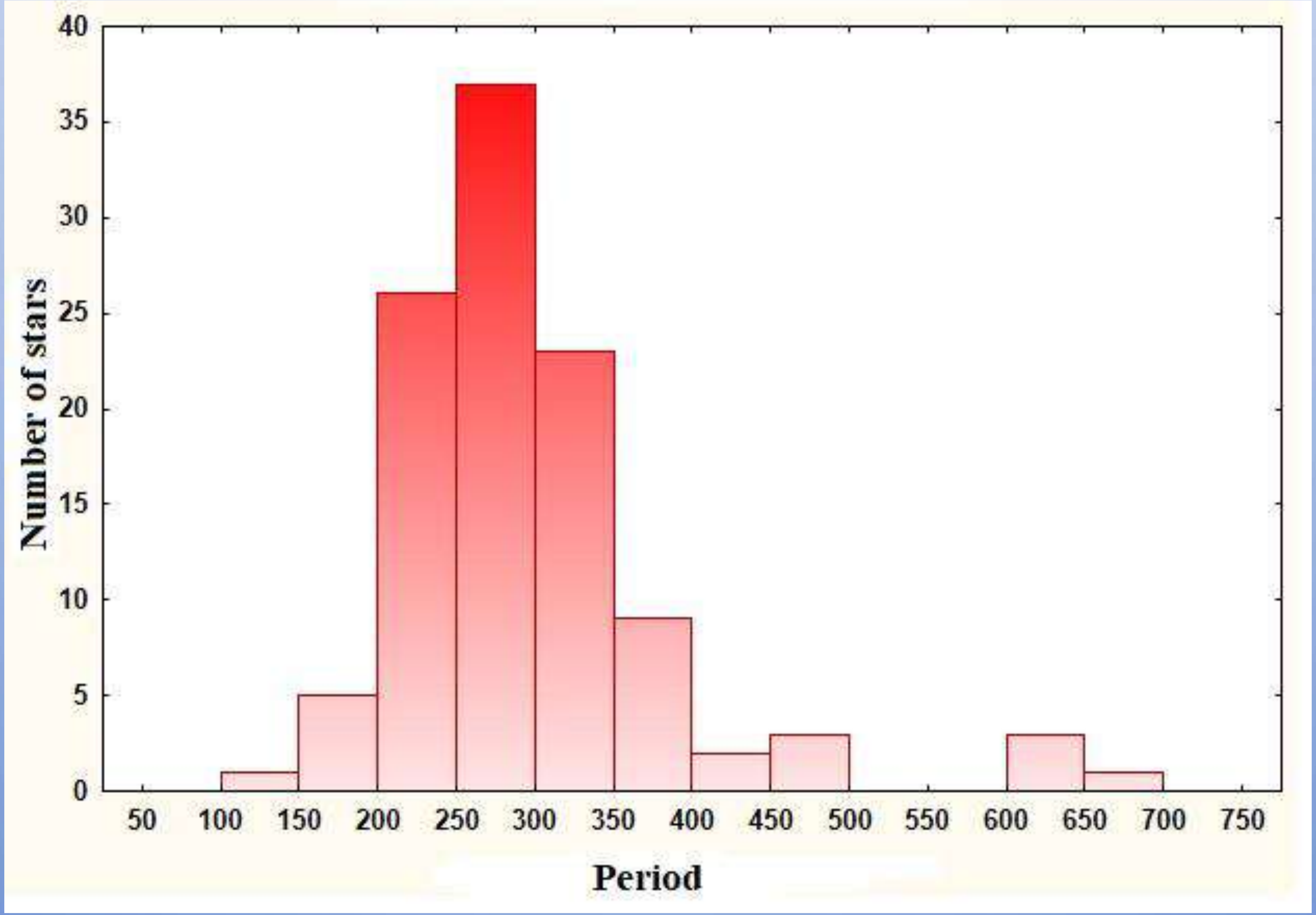


Figure 13. Distribution of the ASAS-SN Periods for 112 FBS M- type Mira variables.

5. Mira Variables

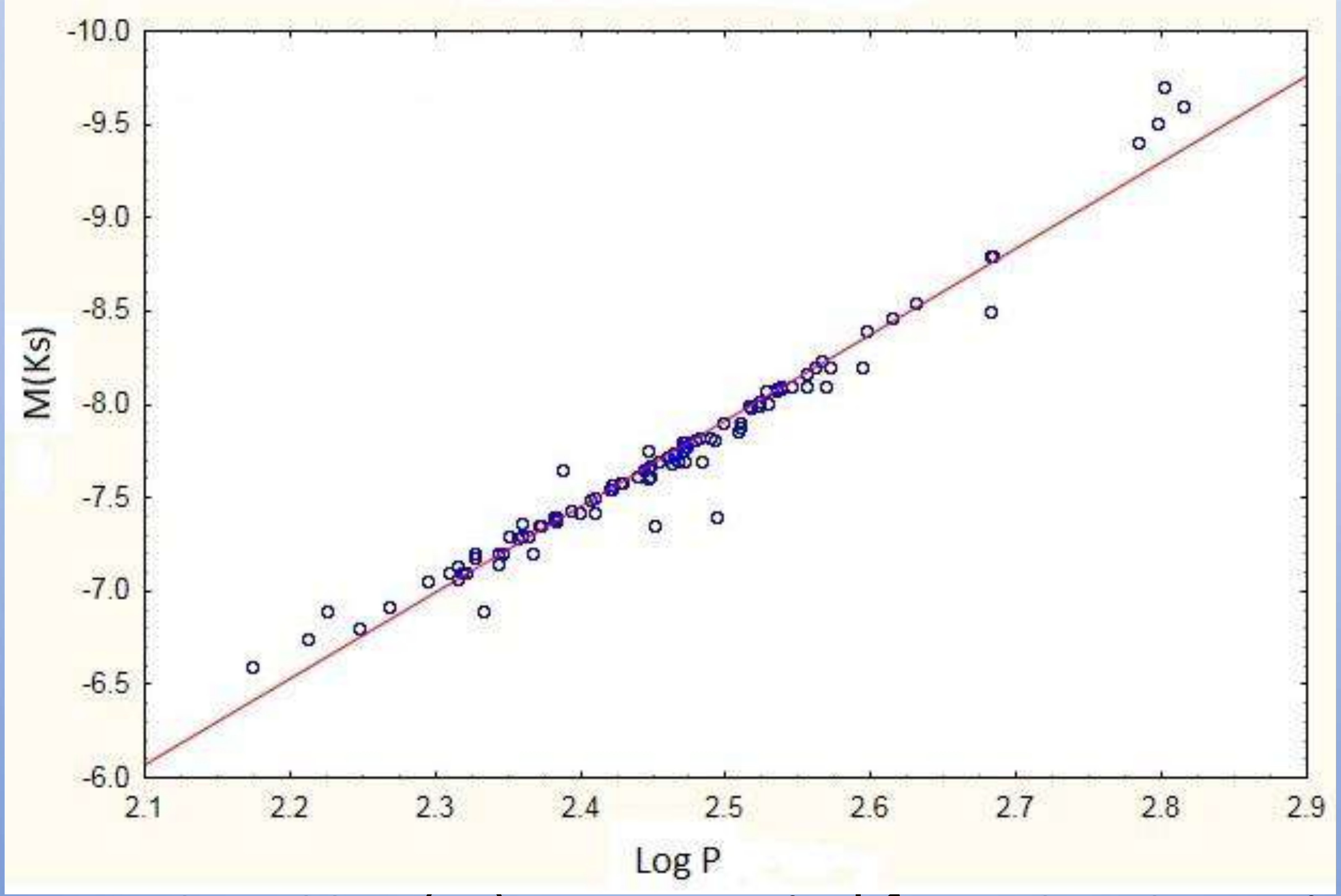


Figure 14. 2MASS M(Ks) versus Period for 112 FBS M Mira variables. The black line is the best fitted line and equation is:

M(Ks) = 3.62 – 4.61 × LogP (for 112 FBS Mira Variables)

6. DISCUSSION AND CONCLUSION

- In this paper we explored the sample of 1096 relatively bright, spectroscopically confirmed M and C-giants from the Second edition of the FBS LTS catalogue including various kinds of long period variables. For this study, we cross-correlated our sample with the data bases from Gaia DR2, the Catalina Sky Survey(CSS), 2MASS, and All-Sky Automated Survey for Supernovae (ASAS-SN). This allowed characterizing the FBS sample in more detail. One of our main goal was to study the location of the spectroscopically confirmed FBS O-rich and C-rich giants in the new diagnostic diagram presented by Lebzelter et al. (2018) combining 2MASS infrared and Gaia DR2 optical photometry. Our conclusions can be summarized as follows:

a) Most of our FBS sample stars are at high Galactic latitudes with a typical distance of 1 kpc from the plane. Therefore, the sample is only mildly affected by interstellar reddening. No difference between Miras and SRVs has been found.

6. DISCUSSION AND CONCLUSION

- b) 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 samples with unknown distances while losing the ability of the Gaia-2MASS diagram to separate the stars according to mass. We found that the FBS giants are mainly low-mass AGB or RGB stars with very few candidates being possibly intermediate-mass AGB stars. For the predominant part of the M giants it can be adopted $M_I < 4M_{\bullet}$. Two M giants, namely FBS 0825+626, J-Ks =2.146 mag., and FBS 2142-089, J-Ks =1.211 mag., are located in group of C-rich stars. Both objects are SR variables and are require more detail investigation in future.

6. DISCUSSION AND CONCLUSION

- c) Using Gaia DR2 distance information provided by Bailer-Jones et al.(2018), we constructed colour-absolutde-magnitude M(G) diagram for nearly 1096 FBS M giants. Absolute magnitudes cover the range $+1.0 \geq M(G) \geq -5.4$ mag. Combining this result with the findings from the Gaia-2MASS diagram and the Galactic distribution of the objects we conclude that the vast majority of the FBS M giants belong to the Galactic thin and thick disk population.
- d) For the M-type Miras, a further characterization can be achives by using their periods. We showed that the observed period distribution of our samples suggest _______

6. DISCUSSION AND CONCLUSION

Our study illustrated the possibilities to investigate samples of red giants using the data bases from large surveys and the Gaia-2MASS diagram. Analogue studies have been carried out on spectroscopically confirmed faint M and C stars noted as periodic variables at high Galactic latitudes in the Catalina (Drake et al. 2014, 2017) and LINEAR (Palaversa et al. 2013) catalogues (Gigoyan et al. 2021, in press). A dominant fraction of these M and C giants belong to the Halo and to arms of the Sagittarius dwarf galaxy (Sgr). The results will appear soon.

Moreover, new diagnostic tool for the investigation of stellar populations of AGB- stars creates numerous of many new projects. As a next step, we are going to use this tool in the near future specially for a large amount of Mira-type variables pulsation periods of which lie in a great range.

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THANK YOU FOR ATTENTION