Investigations of late-type giant stars from the First Byurakan Spectral Sky Survey

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Abstract

We study late-type giants found in the First Byurakan Survey (FBS) data base. The third Gaia data release (Gaia EDR3) photometric and astrometric data have been used to characterize our sample of 1 100 M-type giants and 130 C-type stars found at high latitudes. Phase dependent light-curves from large sky area variability data bases such as Catalina Sky Survey (CSS) and The light curves from the Catalina Sky Survey (CSS), All-Sky Automated Survey for Supernovae (ASAS-SN) and Transiting Exoplanet Survey Satellite (TESS) databases were exploited to study their variability nature. Using TESS light curves, the variability types of some objects have been established for the first time.

Keywords: *late-type -stars: AGB – stars: variables: TESS and Gaia data*

1. Introduction

The First Byurakan Survey (FBS), also known 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 (Markarian, 1967). The spectral plates were obtained at the Byurakan Astrophysical Observatory (BAO) using the 1-m Schmidt telescope. Various Kodak emulsions were used during the observations, providing a spectral range of 3400–6900 Å.

The selection and study of faint late-type stars (LTSs, M-type and carbon (C) stars) at high Galactic latitudes were one of the main priorities of the second part of the FBS. C stars can be identified through the presence of Swan bands of C_2 molecule at 4737, 5165, and 5636 $\mathring{A}$ (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 $\mathring{A}$.

All FBS 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. All DFBS plates were analyzed for LTSs. 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, 241 M dwarfs, and 1100 M-type giants), was generated (Gigoyan et al., 2019).

The main goal of the present paper is the characterization of FBS late-type giants selected on First Byurakan Survey (FBS) plates, using modern astronomical databases, mainly Gaia EDR3 (EDR3; Gaia Collaboration et al., 2021), Catalina Sky Survey (CSS), All-Sky Automated Survey for Supernovae (ASAS-SN)(Jayasinghe et al., 2018, Kochanek et al., 2017, Shappee et al., 2014) and Transiting Exoplanet Survey Satellite (TESS)(Stassun et al., 2019).

Our small paper is structured as follows. Section 2 considers photometric and astrometric data, cross-correlations with *Gaia* EDR3, 2MASS and WISE.

In Section 3 we present the results of light curve analysis and classification of FBS late-type giants. Section 4 summarizes our results.

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[1]http://www.ia2-byurakan.oats.inaf.it for more details, see also the web site at ArAS http://www.aras.am/Dfbs/dfbs.html/

2. Gaia EDR3, 2MASS and WISE photometric data

Gaia EDR3 (Gaia Collaboration; Gaia Collaboration et al., 2021) provides high-precision astrometry, three-band photometry, effective temperatures, and information on astrophysical parameters for about 1.8 billion sources over the full sky brighter than G = 21.0 magnitude. All FBS red giants were cross-matched with the *Gaia* EDR3 catalogue sources. These objects are relatively bright, so that G - band brightnesses were in the range $9.4 < G < 18.2$ mag.

To discriminate dwarf/giant luminosity class, we used the traditional color-color plots (J-H vs. H-Ks). Giant stars are notable for having infrared colors different from the M dwarfs. This has been known since Bessell & Brett (1988) and Bessell (1991). M dwarfs are very well separated on *JHK* Near-IR colour-colour diagram. Figure 1 presents the 2MASS *J-H* versus $H\text{-}K_s$ colour-colour diagrams for all 1471 FBS LTS. Among the FBS M-type stars with the largest 2MASS colours ($J\text{-}H = 2.23$, $H\text{-}K_s = 1.71$) is the object FBS 2216+434, which subtype is estimated M6-M7, and is associated with the unknown source IRAS 22165+4326.

The WISE four band photometry provide useful color indices for giant carbon stars: we show in figure 3 W1-W2 versus W1-W4. Dusty C stars are well separated in a rising branch, while non-dusty C stars are mixed with the other ones. Mira variables are a bit above the main locus of the late type stars. Semiregular variables are spread all along the main locus, while nonvariable stars are grouped in the blue corner.

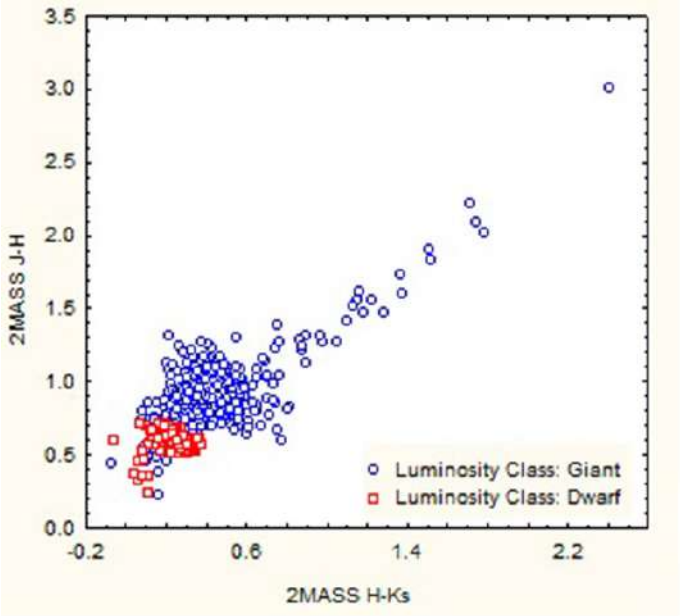

Figure 1. The 2MASS *J-H* versus $H\text{-}K_s$ colour-colour diagram for 1471 FBS LTSs stars.

3. Optical variability

To study optical variability for FBS late-type giant stars, the basic data coming from the three most prominent and wide-area sky surveys were used and considered: the Catalina Sky Survey (CSS, second public data release CSDR2, accessed via http://nesssi.cacr.caltech.edu/DataRelease/, 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)) and Transiting Exoplanet Survey Satellite (TESS).

3.1. Catalina Sky Survey

The CSS comprises two main parts surveying the Northern (Drake et al., 2014) and the Southern (Drake et al., 2017) sky, respectively. Both surveys were analyzed by the Catalina Real-Time Transient Survey (CRTS) in search for optical transient ($V < 21.5$ mag) phenomena. CSS was used as the primary source for attributing variability types, periods, and amplitudes to the FBS giant carbon stars. The light curve analysis confirms nine stars as Mira-type variables, 43 as Semi-Regulars (SR) with very well expressed periodicity,

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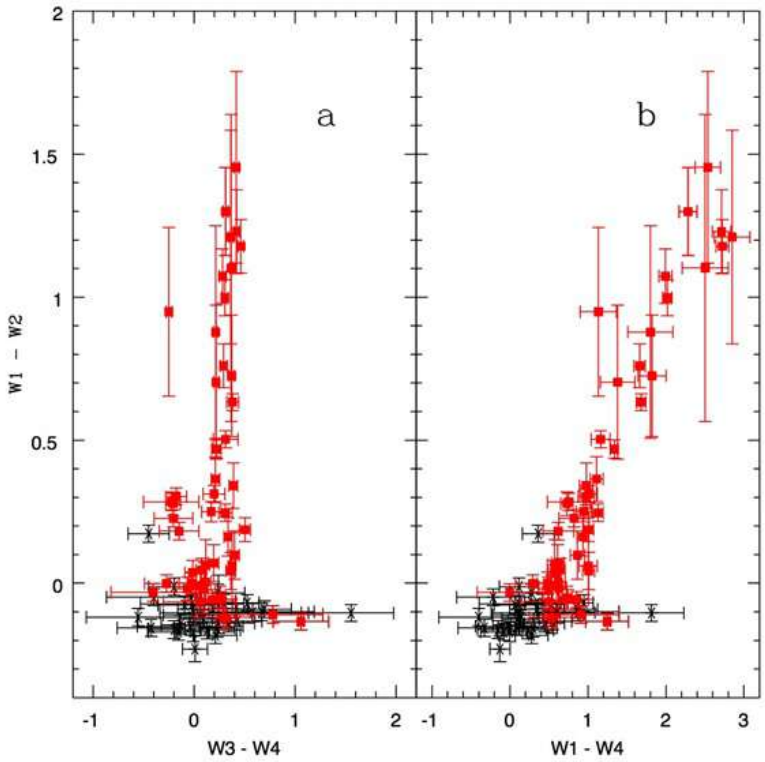

Figure 2. WISE W1-W2 vs. W3-W4 and WISE W1-W2 vs. W1-W4 color-color plots (with error bars) for all C stars. Crosses are early type stars, filled squares are late N-type AGB stars.

and two objects as Irregular (Irr)-type variables. The variability types of 27 stars are presented for the first time.

3.2. ASAS-SN

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 missing 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, 299 L-type and 111 Mira-type variables. The period of a Mira increases with increasing luminosity, and hence depends on its mass and its evolutionary status along the AGB. Thus, longer period Miras tend to correspond to higher masses (see Figure 6 in Hughes & Wood (1990)). Periods for the 111 FBS M-type Miras have been taken from the ASAS-SN data base. All these periods were checked by visual inspection of the light curves and corrected in some cases. The periods are between 250 and 300 days with hardly any Miras showing periods above 400 days. This suggests that the FBS Mira sample mainly consists of low mass AGB stars with a typical mass around 1 M_Sun.

3.3. TESS

NASA's Transiting Exoplanet Survey Satellite (TESS) is an all-sky space-based mission designed to search for planets transiting around nearby M dwarfs (Ricker et al., 2014). Its observed ~73% of the sky across 26 sectors, each lasting 27.4 days and covering a 24° × 96° field of view. TESS observed a number of stars at 2-mn cadence and collected full frame images (FFIs) every 30 minutes, covering the entire mission phase. By the end of 2 two-year primary mission, TESS identified 2241 exoplanet candidates (Guerrero et al., 2021), known as TESS Objects of Interest (TOIs).

For the M-type giants that do not have light curves in ASAS-SN, TESS light curves are analyzed. 32 red giants have light curves. Three stars have no data in the catalogs of variable stars. There is a light curve only for FBS 1752+666 of these three stars in CSS. Figure 4 and figure 5 present light curves of CSS and

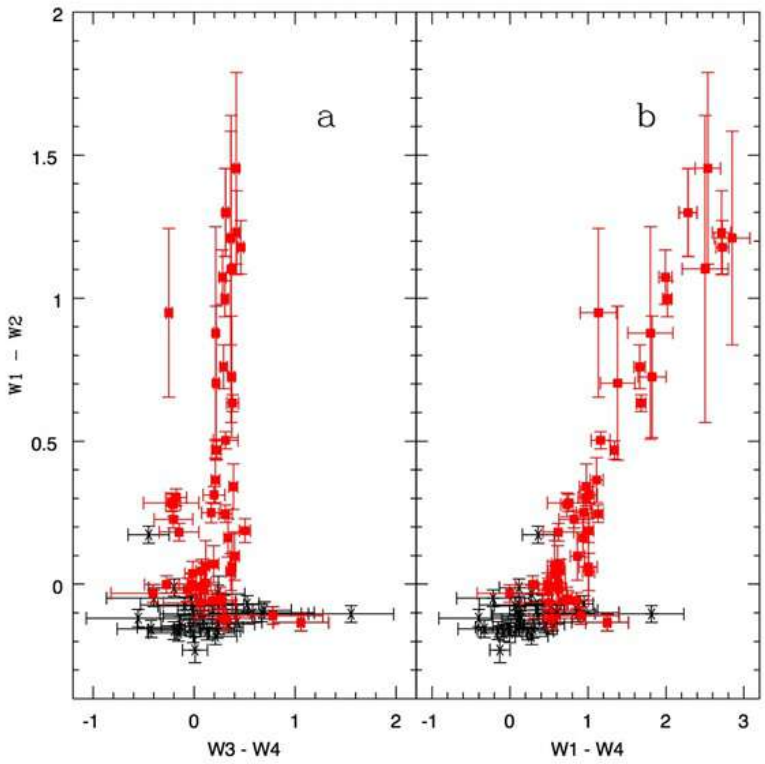

Figure 3. WISE W1-W2 vs. W3-W4 and WISE W1-W2 vs. W1-W4 color-color plots (with error bars) for all C stars. Crosses are early type stars, filled squares are late N-type AGB stars.

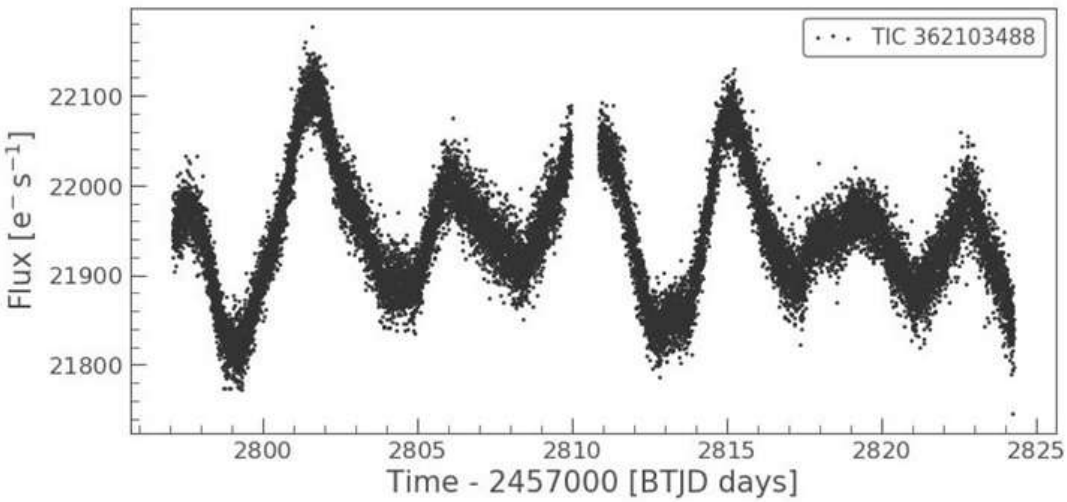

Figure 4. Light curve of CSS for FBS 1752+666.

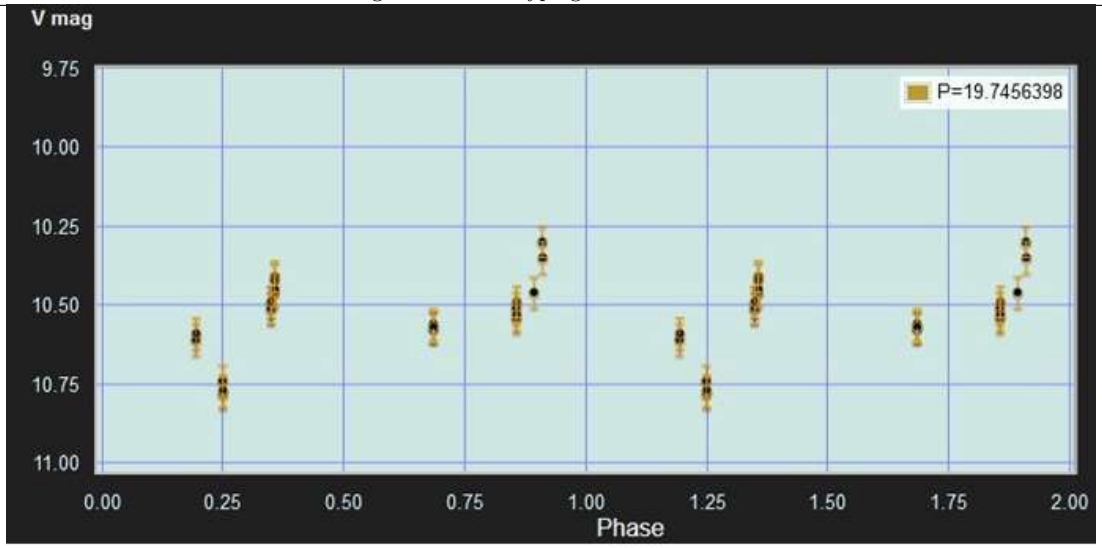

Figure 5. Light curve of TESS for FBS 1752+666 .

TESS of FBS 1752+666. The light curve analysis confirms that this object is Semi-Regular (SR) variable with very well expressed periodicity. The variability type FBS 1752+666 is presented for the first time. The amplitude of variability is 0.4^m, the period is 19.74 days. The lightkurve package based on Python was used to analyze the TESS light curve (Barentsen et al., 2019).

4. Discussion and conclusion

For study the red giants identified in the First Byurakan Survey (FBS) low-resolution spectroscopic database, Gaia EDR3 high-accuracy astrometric and photometric data were used. These objects are relatively bright, so that G - band brightnesses were in the range $9.4 < G < 18.2$ mag.

Variability study is one aspect of our programs aimed to investigate FBS red giants. We have examined optical variability using the three most prominent wide-area sky surveys, the CSS, ASAS-SN and TESS, to clarify their variability nature.120 objects are Mira-type variables, 734 are SR, and 301 are Irr-type variables. The light curve analysis confirms FBS 1752+666 as Semi-Regular (SR) with very well expressed periodicity. The variability type FBS 1752+666 is presented for the first time. The amplitude of variability is 0.4^m, the period is 19.74 days.

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