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DISCOVERY OF A NEW [WR] STAR

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ABSTRACT. Wolf–Rayet (WR) stars are evolved massive objects, famous for their spectra rich with emission lines. For the first time WR stars were described more than 150 years ago, and now in our Galaxy we know around 667 objects of this type. However, the discovery of a new WR star, especially based on spectral observations, is still a rare event. The paper is devoted to J040901.83+323955.6 star, discovered a few years ago as WR star in LAMOST spectral survey by machine learning methods. We were interested that different researchers based on different methods classify this object in different ways – ranging from RR Lyr variable to nitrogen rich WR – and so we began our study. We combined spectral and archival photometric data, analysed the spatial location of the star in the Galaxy and concluded what J040901 is [WR] – central star of a planetary nebula.

Keywords: stars: Wolf–Rayet; stars: low-mass; stars: variables: general

АНОТАЦІЯ. Зорі Вольфа-Райє (WR) – це масивні об'єкти, що проеволюціонували, спектри яких багаті емісійними лініями, що свідчать про високий темп втрати маси. Хоча вперше зорі WR були описані понад 150 років тому, зараз у нашій Галактиці відомо лише 667 об'єктів цього типу. Тому відкриття кожної нової зорі WR, особливо з урахуванням спектральних спостережень, є рідкісною подією. Стаття присвячена зорі J040901.83+323955.6, виявленій кілька років тому у спектральному огляді телескопа LAMOST методами машинного навчання та класифікованою як WR зоря. Нас зацікавило, що різні дослідники на основі різних методів класифікують цей об'єкт по-різному – від змінної RR Lyr до багатої на азот WR – і ми почали наше дослідження. Ми визначили положення зорі на діаграмі колір-величина і виявили, що J040901.83+323955.6 знаходиться в області маломасивних зір. На підставі цього робимо висновок, що J040901.83+323955.6 є [WR] – центральною зорею планетарної туманності. Для вивчення її фотометричної змінності ми поєднали дані з різних оглядів неба. Побудовані криві блиску явно показують, що зоря дуже змінна, амплітуда змінності досягає 0.5 зор. величини.

Ключові слова: Вольф-Райє , низькі маси, змінні, загальний

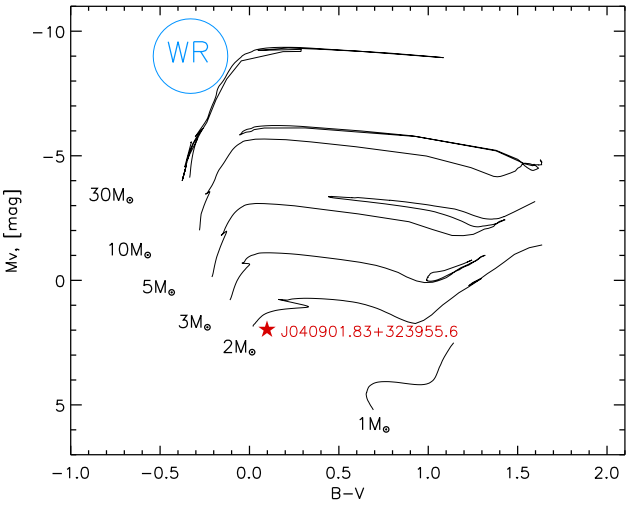

Figure 1: Position of J040901.83+323955.6 in the color–magnitude diagram

1. Introduction

Wolf–Rayet (WR) stars are final point in evolution of massive stars. Location of WR in the Galaxy coincides with spiral arms and star formation regions. Therefore, the discovery of new WR stars in the Galaxy via optical observations has been severely limited by dust extinction. Due to that, most of discoveries of new WR stars nowadays happen in infrared (IR) range. Although the probability of finding a WR star during an optical spectroscopic survey still remains.

Star J040901.83+323955.6 was discovered by Škoda et al (2020) during large spectroscopic survey based on LAMOST archive and classified as WN star. Independently Sun et al. (2021) found J040901 in the

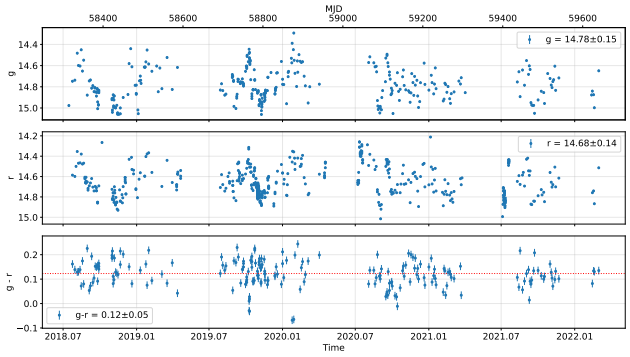

Figure 2: The light curve of J040901.83+323955.6 based on the data from ZTF DR12

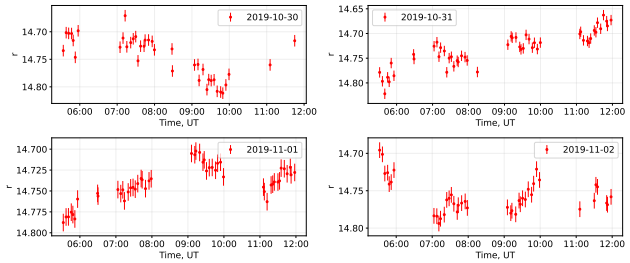

Figure 3: Intra-night variability of J040901 for the four nights based on ZTF DR12

frame of a search for new cataclysmic variables (CVs) in LAMOST data and classified it as Nova-like subtype of CVs. Sun et al. (2021) suggested that J040901.83+323955.6 is surrounded by a disk, because Hα line in its spectrum shows double-peaked profile. Photometric studies of J040901 are also known: Sesar et al. (2017) added J040901 to the list of RR Lyrae stars using machine-learning methods and multi-epoch, asynchronous multi-band photometric data from Pan-STARRS for identification. They found a period P=0.2847 d for the object. Moreover, J040901 was included in the first catalog of variable stars of the All-Sky Automated Survey for Supernovae (ASAS-SN) survey as a variable (Jayasinghe et al. 2018). In the catalog the star is mentioned as a non-periodic object with V=14.48 mean magnitude and amplitude of 0.39 mag.

2. J040901.83+323955.6 in color-magnitude diagram

We started our study of J040901 with the analysis of location of the star in color-magnitude diagram (Figure 1). We recalcultated visible V magnitude of the star to absolute M_V magnitude using distance estimations according to *Gaia* third Data Releases (DR3; Bailer-Jones et al. 2021). Figure 1 clearly shows that J040901 lies in the region of low mass stars and the object significantly differs from WR stars in magnitude.

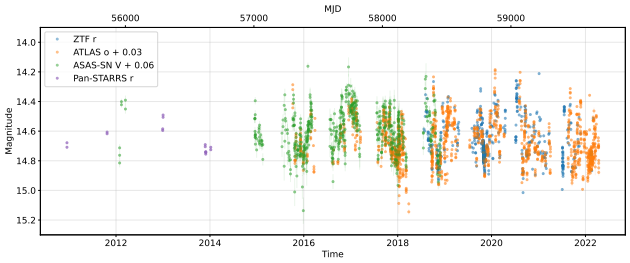

Figure 4: The light curve of J040901.83+323955.6 over last 10 years using the data from ZTF, ATLAS, ASAS-SN and Pan-STARRS sky surveys.

Ii is possible to explain low mass of J040901 and its WR type spectrum if one suggests that the object is a [WR] star. [WR] stars or Wolf-Rayet central stars of planetary nebula (WR CSPN) are objects with *WR phenomenon*. *WR phenomenon* is a fast-moving, hot plasma, normally expanding around a hot star.

3. Photometry and variability

In order to assess the photometric variability of the star we utilized the data from several large-scale sky surveys and public data archives.

The position of J040901 has been repeatedly observed during Zwicky Transient Facility (ZTF, Bellm et al. 2019) survey. The light curve of the object contains 1026 measurements in ZTF g and r filters. We converted them to Pan-STARRS photometric system by using the color terms from the data table, and mean object color $g - r = 0.12$. We then grouped together the measurements in g and r filters separated by no more than 0.3 days (0.05 days on average) to get the color as a function of time. Figure 2 shows the light curves in two bands based on ZTF data, as well as the color. Both the color and magnitudes vary on quite short, most probably intra-night time scale, as illustrated by Figure 3 that shows the light curves of four nights when the field of the object was observed repeatedly in r band.

We also found the data from the archive of Asteroid Terrestrial-impact Last Alert System (ATLAS) (Heinze et al. 2018, Smith et al. 2020, Tonry et al. 2018). We used only o band data (1395 points) with S/N > 10, which we converted to Pan-STARRS photometric system using $r = o + 0.26 \cdot (g - r) = o + 0.03$ equation from Tonry et al. (2018) and $g - r = 0.12$ mean object color.

The ASAS-SN (Shappee et al. 2014) routinely monitors the whole sky. We downloaded from its Light Curve Server (Kochanek et al. 2017) the forced aperture photometry ($16''$ radius) light curve with zero point calibrated to APASS DR9 catalogue zero

point for all epochs available in the service. We then kept only 607 V band measurements with S/N > 10. All these data, converted to Pan-STARRS r band, are shown in Figure 4.

4. Conclusions

J040901 is an evolved low mass star showing WR phenomenon, but not a massive WR star. J040901 shows strong short timescale photometric variability ($\sim$0.5 mag). We are going to continue the study based on new spectral data and numerical modeling.

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