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Gaia EDR3 Data For Three Young Stellar Objects

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Abstract

We present Gaia Early Data Release 3 (Gaia EDR3) high accurate astrometric and photometric data and also Catalina Sky Survey (CSS) phase-dependent light curves for three Young Stellar Objects (YSO). **They are LRL 245, 2MASS J04300424+3533238, and CVSO 592. These tree YSOs are presented as periodic variables in the Catalina Surveys Data Release-1 (CSDR1) data base.** CSS phase-dependent curve of LRL 245 shows periodicity with period P=234.66 days and amplitude Δm$\approx$4.0 mag. For this object high-resolution spectra in H-band (from 1.51 to 1.69 μm) was obtained by the APOGEE instrument. LAMOST telescope moderate-resolution CCD spectra is available for object 2MASS J04300424+3522238 only. **The spectra shows clear features of M dwarfs.**

Keywords: *Young Stellar Objects-Variability-Gaia EDR3 data-**Individual Objects: LRL 245, 2MASS J04300424+3533238, and CVSO 592***

1. Introduction

The study of variable stars is one of the most popular and dynamic areas of modern astronomical research. Variability is the property of the most stars, and as such, it has a great deal to contribute to our understanding of them. It provides researches with many additional and important parameters (periods, amplitudes, etc.) which are not available for non-variable stars. These important physical parameters can be used to deduce characteristics of the stars. The study of variability also allows us to directly observe changes in the stars: both the rapid and sometimes violent changes associated especially with stellar birth and death, and also the slow changes associated with normal stellar evolution. An overview of variable stars, including an introduction to variable stars in general, the techniques for discovering and many-sided studying variable stars, and description of the main types of variable stars are presented in more detail in the book by Percy (2007).

Variability has been defining characteristic of young pre-main-sequence (PMS) stars. These fluctuations occur not only over a wide range of timescales but over a wide range of wavelengths and have been used to deduce various properties of these systems. Daily to weekly optical fluctuations up to 1.0÷2.0 mag are common (Herbst et al., 1994).

PMS variables are often called nebular variables, because, being young, they are usually found near the nebulae from which the stars are born. A PMS star could also be an eclipsing or rotating variable if it had a close companion or a spotted surface. It could even be a pulsating variable if it was located in an instability strip.

In our paper, we present new data for three well-studied Young Stellar Objects (YSO), namely for LRL 245, 2MASS J04300424+3522238, and CVSO 592 from the early installment of the third Gaia data release (Gaia EDR3, **see Chapter 2.2**). These objects are presented as periodic variables in Catalina Surveys Data Release - 1 (CSDR1, Drake et al., 2014) database. **These three periodic variables (out of 1184) presented by Gigoyan et al. (2021) were associated in the SIMBAD database with the YSO (e.g., Gutermuth et al., 2009, Hernández et al., 2007).**

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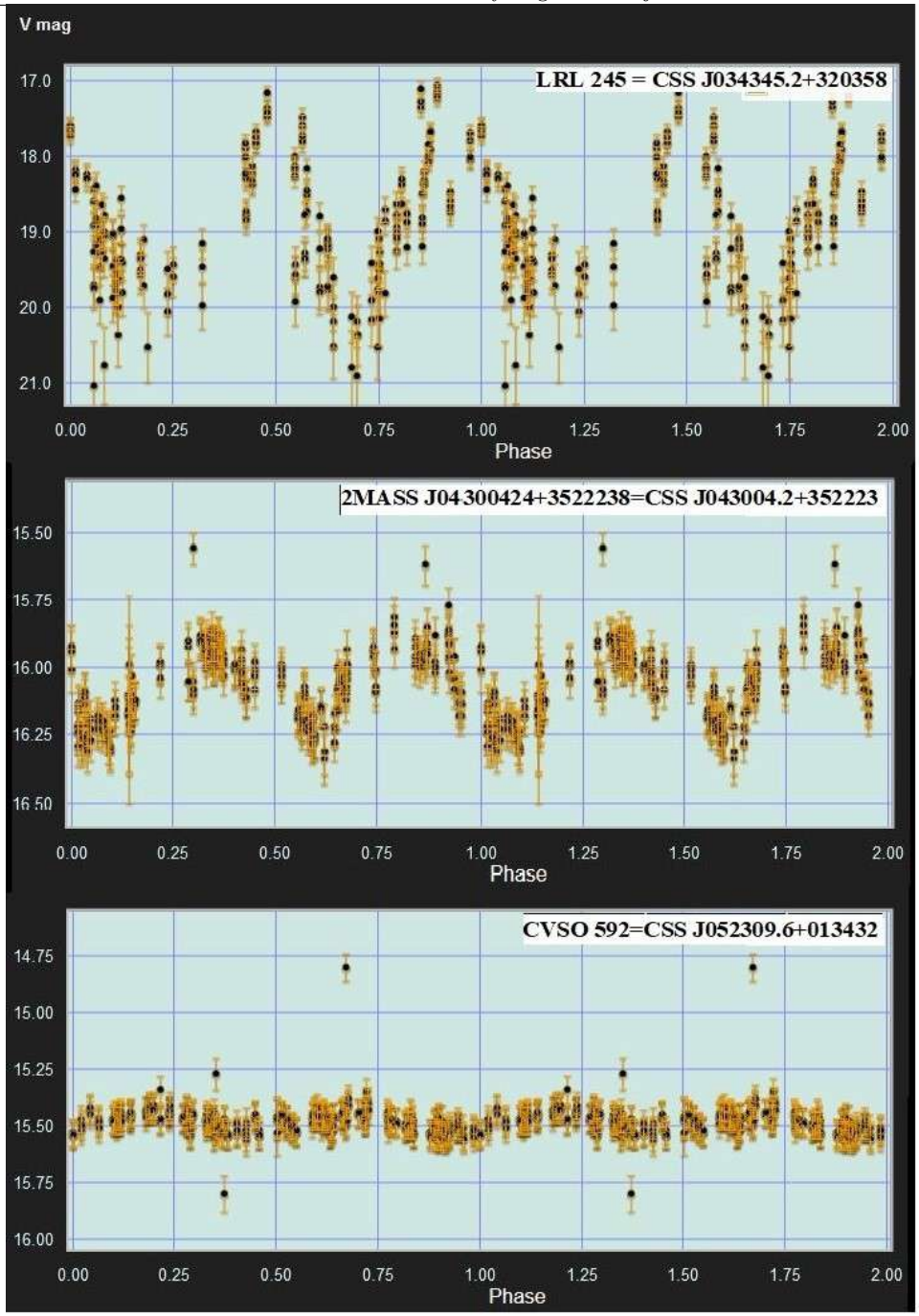

Figure 1. CSS phase-dependence light-curves of three YSOs (accessed via http://nesssi.cacr.caltech.edu/DataRelease/)

2. Data Used

2.1. The Catalina Sky Survey Data

The Catalina Sky Survey (CSS) data are provided by three telescopes. All the Catalina data are analyzed for transient sources by the Catalina Real-Time Transient Survey (CRTS, Drake et al., 2009). Drake et al. (2014) presented a catalogue of periodic variables selected from CSDR1. The catalogue contains data for 47055 variable objects ("Catalina Survey Periodic Variable Stars", SIMBAD VizieR Catalogue J/ApJS/213/9).

Spectral classes and physical parameters are presented for optically faint periodic variables taken from the CSDR1 (Drake et al., 2014) and LINEAR (Palaversa et al., 2013) data sets. A catalogue containing multi-parameter data on 1184 periodic variables from modern astronomical low and moderate-resolution, spectroscopic and photometric database was generated (Gigoyan et al., 2021, SIMBAD CDS VizieR Catalogue J/other/Ap/64.27). The periods are in range $10 \leq P \leq 1504$ days and

Catalina magnitudes are in range $11.5 \leq V \leq 20.0$ mag. This catalogue contains also alternative names of objects from the SIMBAD database, references, and spectral classes if possible or elsewhere.

2.2. Gaia EDR3 Data

The Gaia satellite executes an ambitious project of the European Space Agency (ESA) to record astrometric, photometric and spectroscopic data of more than one billion objects in the Galaxy and the Local Group up to G = 21 (Gaia Collaboration et al., 2018). We used Gaia Early Data Release 3 (Gaia EDR3) high accurate astrometric and photometric data.

3. Results and Discussion

Table 1 presents data for the three CSS periodic variables. The columns are as follows: (1) CSS Number, (2) CSS average V-band magnitude and amplitude of variability, (3) Period (in days), (4) the YSOs Name in SIMBAD database.

Table 1. CRTS data for three YSOs

CSS Number	<V> mag	Period (in days)	YSO Name
J034345.1+320358	18.49 (4.00)	234.660	LRL 245
J043004.2+352224	16.10 (0.35)	10.606	2MASS J04300424+3522238
J052309.6+013432	15.48 (0.10)	11.871	CVSO 592

Figure 1 presents CSS phase-dependent light curves for three YSOs. We note that in the ASAS-SN variability database (Kochanek et al., 2017, Shappee et al., 2014, online access via https://asas-sn.osu.edu/variables/) there are also monitored data for objects 2MASS J04300424+3522238 and CVSO 592 (ASASSN -V J043004.20+352224.1 and ASASSN-V J052309.62+013432.4). In the ASAS-SN variability database, both objects are classified as rotating variables.

Table 2 contains some important Gaia EDR3 (Gaia Collaboration et al., 2021, SIMBAD CDS VizieR Catalog I/350/gaiaedr3) data for three YSOs. We present also the distance information derived from Gaia EDR3 by Bailer-Jones et al. (2021, CDS VizieR Catalog I/352/gedr3dis) for these three YSOs.

The columns are as follows: (1) YSO name in SIMBAD data base; (2) Gaia EDR3 name; (3-5) Gaia EDR3 wide-band G magnitude; BP mag; BP-RP color; (6-7) consequently median of the geometric and photogeometric distances (Bailer-Jones et al., 2021).

Table 2. Gaia EDR3 data for three YSOs

YSO Name	Gaia EDR3 ID	G mag	BP mag	BP-RP mag	R(pc) geom.	R (pc) photogeom.
LRL 245	216679729989231744	20.318	21.386	2.621	164(±50)	977(±175)
2MASS J04300424+3522238	173380030079919488	16.541	18.110	2.823	533(±25)	525(±25)
CVSO 592	3222177481567112064	15.518	16.778	2.837	355(±6)	357(±9)

Table 3. Reddening data for three YSOs

YSO Name	E(B-V) mag	A_V mag	A_{K_s} mag	$M(K_s)$ mag
LRL 245	3.041(±0.479)	10.031	1.06	3.92
2MASS J04300424+3522238	11.104(±7.509)	37.081	3.88	−0.59
CVSO 592	0.113(±0.004)	0.352	0.039	4.16

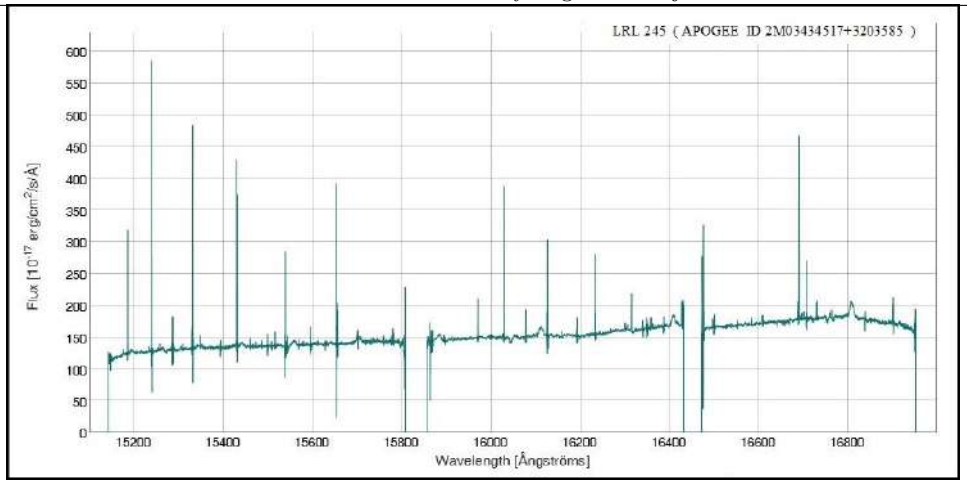

Figure 2. APOGEE high-resolution spectra for object LRL 245. The APOGEE identification is 2M03434517+3203585 (SIMBAD CDS Catalogue III/284/allstars, Jönsson et al., 2020).

The LRL 245 is the faintest object among the three YSOs (Table 1 and 2) and deserve a special attention for variety of reasons. This object show very high infrared excess which are typical for dusty evolved Asymptotic Giant Branch (AGB) stars. Azimlu et al. (2015) presented 2MASS K_s mag plotted versus WISE 22 μm for 353 point sources (Figure 8 for known YSOs and candidates). In their diagram sources are divided into two main populations. Sources with the same W4 magnitude are divided into two brightness branches in K_s mag, the "lower group" and "upper group". The "lower group" usually consists of bright stars. Known YSOs and YSO candidates lie in the "upper group", with larger K_s magnitudes. Extreme brightness in K_s mag of the lower population suggests that they can be dusty evolved stars. To characterize this "lower population", these authors compared them with the known AGB stars. In Figure 8 these authors matched also all known evolved stars in the Galaxy (including AGB stars, carbon stars, and Mira variables) from SIMBAD with the WISE catalog. Having the apparent 2MASS K_s = 11.009 mag and WISE (22) = 2.265 mag, the object LRL 245 lies in the "upper group" in Figure 8 by Azimlu et al. (2015), where some amount AGB stars also exist.

Adopting the Gaia EDR3 distances (Bailer-Jones et al., 2021) the 2MASS K_s magnitude is estimated for YSOs of Table 1. We estimate 2MASS absolute K_s-band magnitude via the usual equation:

$$M(Ks) = K_s - 5Log_{10}R + 5 - A(K_s), \quad (1)$$

The interstellar E(B-V) color excess is used to take into account Galactic extinction. The color excess is provided by NASA/IPAC Galactic Dust Reddening Extinction service at https://irda.ipac.caltech.edu/application/DUST.

Table 3 present extinction data for three YSOs. In above noted data base we used according to Schlafly & Finkbeiner (2011) extinction map only, assuming a visual extinction to reddening ratio A_V/E(B-V) = 3.1. We adopt also $A_{K_s} = 0.35\times$E(B-V).

The M(K_s) can be estimated as 3.92 mag, and 4.16 mag, adopting the geometric distances 164 pc and 355 pc, consequently for LRL 245 and CVSO 592. Such values is typical for main-sequence K-type stars (Cifuentes et al., 2020). Below we present some notes to individual objects.

(a) LRL 245 is in a well-studied **star-forming cluster IC348 in Perseus.** Cieza & Baliber (2006) presented the *Spitzer* Infrared Array Camera (IRAC; 3.6, 4.5, 5.8, and 8.0 μm) observations for this object which is a part of the c2d legacy project of the IC348 members. Azimlu et al. (2015) estimated M = 2.05±0.25M_{Sun} for LRL 245. As a model grid, they used the method to analyse the spectral energy distributions models (SED) of YSOs developed by Robitaille et al. (2006). The star formation rate in the Perseus Complex is estimated by Mercimek et al. (2017). High-resolution near-infrared spectra for object LRL 245 have been obtained by APOGEE (Apache Point Observatory Galactic Evolution Experiment) spectrograph, which is mounted on the 2.5 m Sloan Digitak Sky Survey (SDSS) telescope (Blanton et al., 2017, Gunn et al., 2006). The APOGEE instrument covers the range from 1.51 to 1.7 μm with a typical resolution R∼22500. The SDSS DR16 contains APOGEE spectra for about 430000 stars covering both the northern and southern sky, from which radial velocities (RV), stellar parameters, and chemical abundances of up

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to 26 species are determined by Jönsson et al. (2020). The object LRL 245 show periodic variability with amplitude Δm$\sim$4.0 mag (Figure 1). For this object there are no spectra class information in the SIMBAD database.

(b) 2MASS J04300424+3522238: Near-infrared, mid-infrared data also Echelle high-resolution spectroscopy (on the 3.5 m Canada-France-Hawaii Telescope, CFHT) in the range 3500 to 10500 Å at a resolution 68000, **was obtained for this object and is presented by Cieza et al. (2012).** This object is classified as an M0 – subtype star but spectra are not included in the paper by Cieza et al. (2012). SED for this object is presented also as a giant planet-forming disk candidate.

Figure 3 presents LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope) moderate-resolution CCD spectra (LAMOST DR5, Luo A-L et al. 2019, spectra available on-line at http://dr5.lamost.org/search/) for YSO 2MASS J04300424+3522238. The lines H_α (λ6563Å), NaD(λ5893Å) and MgH band at λ5198Å are well expressed, which are good indicators for M dwarfs (Gray & Corbally, 2009, Johnson et al., 1986).

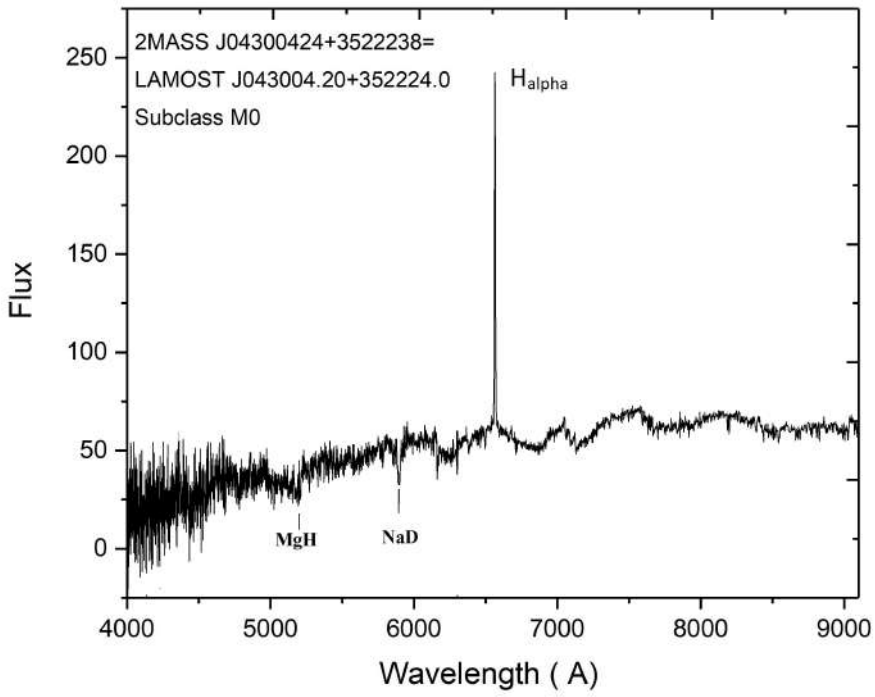

Figure 3. LAMOST moderate-resolution CCD spectra for YSO 2MASS J04300424+3522238 in the range λ4000-9100 Å. The lines H_α and NaD also MgH band are well expressed.

(c) CVSO 592 (Centro de Investigaciones de Astronomia Variability Survey of Orion -CVSO, Briceño et al., 2001, 2005). Bricento et al. have carried out a large-scale survey encompassing $\sim$180 square degree across the Orion OB1 association, with the goal of identifying and characterizing the PMS stars in this extended star-forming complex. This object is a low mass PMS Weak-line T Tau-type star in Orion OB1 association, subclass- M3e (Briceño et al., 2019).

4. Summary And Conclusion

We present for the first time some important the Gaia EDR3 photometric data, Catalina Sky Survey phase dependent light curves and 2MASS absolute K-band magnitudes for three well studied YSOs, presented in the CSDR1 data base as periodic variables. The objects 2MASS J04300424+3522238 and CVSO 592 are classified in ASAS-SN database as rotating variables and are classified as M0 and M3e dwarfs consequently. The object LRL 245 show very large infrared color indices and CSS phase -dependent light curve with period P=234.66 days and amplitude Δm$\approx$4.0 mag and deserve a special interest. Such colors are typical for dusty evolved AGB. From this point of view highly desirable is to have a spectral type of this object.

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