VVV-WIT-07: another Boyajian's star or a Mamajek's object?*

R. K. Saito¹,[†] D. Minniti^{2,3,4}, V. D. Ivanov⁵, M. Catelan^{6,3}[‡], F. Gran^{6,3} R. Baptista¹, R. Angeloni^{7,8}, C. Caceres^{2,9}, J. C. Beamin^{10,11}

¹Departamento de Física, Universidade Federal de Santa Catarina, Trindade 88040-900, Florianópolis, SC, Brazil

²Departamento de Fisica, Facultad de Ciencias Exactas, Universidad Andres Bello, Av. Fernandez Concha 700, Las Condes, Santiago, Chile ³Instituto Milenio de Astrofísica, Santiago, Chile

⁴ Vatican Observatory, V00120 Vatican City State, Italy

⁵ European Southern Observatory, Karl-Schwarszchild-Str. 2, D-85748 Garching bei Muenchen, Germany

⁶Instituto de Astrofísica, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, 782-0436 Macul, Santiago, Chile

⁷Instituto de Investigación Multidisciplinar en Ciencia y Tecnología, Universidad de La Serena, Avenida Raúl Bitrán 1305, La Serena, Chile

⁸Departamento de Física y Astronomía, Universidad de La Serena, Avenida Cisternas 1200 Norte, La Serena, Chile ⁹ Núcleo Milenio Formación Planetaria - NPF, Universidad de Valparaíso, Av. Gran Bretaña 1111, Valparaíso, Chile

¹⁰Instituto de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Ave. Gran Bretaña 1111, Playa Ancha, Valparaíso, Chile. ¹¹Núcleo Astroquímica y Astrofísica, Facultad de Ingeniería, Universidad Autónoma de Chile, Chile

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

We report the discovery of VVV-WIT-07, an unique and intriguing variable source presenting a sequence of recurrent dips with a likely deep eclipse in July 2012. The object was found serendipitously in the near-IR data obtained by the VISTA Variables in the Vía Láctea (VVV) ESO Public Survey. Our analysis is based on VVV variability, multicolor, and proper motion (PM) data. Complementary data from the VVV eXtended survey (VVVX) as well as archive data and spectroscopic follow-up observations aided in the analysis and interpretation of VVV-WIT-07. A search for periodicity in the VVV $K_{\rm s}$ -band light curve of VVV-WIT-07 results in two tentative periods at $P \sim 322$ days and $P \sim 170$ days. Colors and PM are consistent either with a reddened MS star or a pre-MS star in the foreground disk. The near-IR spectra of VVV-WIT-07 appear featureless, having no prominent lines in emission or absorption. Features found in the light curve of VVV-WIT-07 are similar to those seen in J1407 (Mamajek's object), a pre-MS K5 dwarf with a ring system eclipsing the star or, alternatively, to KIC 8462852 (Boyajian's star), an F3 IV/V star showing irregular and aperiodic dips in its light curve. Alternative scenarios, none of which is fully consistent with the available data, are also briefly discussed, including a young stellar object, a T Tauri star surrounded by clumpy dust structure, a main sequence star eclipsed by a nearby extended object, a self-eclipsing R CrB variable star, and even a long-period, high-inclination X-ray binary.

Key words: Surveys – Catalogues – Infrared: stars – Stars: individual: VVV-WIT-07 - Stars: individual: KIC 846282 - Stars: individual: J1407

 \star Based on observations taken within the ESO Public Surveys VVV and VVVX, Programme IDs 179.B-2002 and 198.B-2004, respectively, and on observations obtained at the Southern Astrophysical Research (SOAR) telescope, which is a joint project of the Min. da Ciência, Tecnologia, Inovações e Comunicações (MCTIC) do Brasil, the U.S. National Optical Astronomy Observatory (NOAO), the University of North Carolina at Chapel Hill (UNC), and Michigan State University (MSU).

E-mail: saito@astro.ufsc.br

‡ On sabbatical leave at the Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstr. 12-14, 69120 Heidelberg, Germany, and European Southern Observatory, Av. Alonso de Córdova 3107, 7630355 Vitacura, Santiago, Chile.

2 R. K. Saito et al.

1 INTRODUCTION

In recent years, a number of variable stars have been identified in ongoing wide-field variability surveys, which have given rise to new classes of variability and expanded our views about the variable Universe. Examples of that are the Slowly Pulsating B-type Stars (SPBs; Mowlavi et al. 2013), the Blue Large-Amplitude Pulsators (BLAPs; Contreras Peña et al. 2017) and the McNeil's Nebular Objects (MNors; Pietrukowicz et al. 2017). Some of these objects are rare/unique in their nature, such as KIC 8462852 (the Boyajian's star, Boyajian et al. 2016) and J1407 (= V1400 Cen, Mamajek et al. 2012). Synoptic surveys are major contributors to these discoveries and much more will certainly come out with the advent of LSST (Ivezic et al. 2008) and the next generation of time-series space missions, including TESS (Ricker et al. 2015) and PLATO (Rauer et al. 2014).

The VISTA Variables in the Vía Láctea (VVV) is an ESO variability survey of the inner Milky Way, which mapped about 562 sq. deg in the bulge and southern Galactic disk (Minniti et al. 2010; Saito et al. 2012). Focused on unveiling the 3-D structure of the Milky Way using pulsating RR Lyrae and Cepheid variables as distance indicators, the VVV data are also being mined on the search for microlensing events, eclipsing binaries, pre main sequence (MS) variables, etc. In 2016 a complementary survey to VVV called VVV eXtended Survey (VVVX, Minniti 2018) started observations, including revisiting the original VVV area thus expanding the original time baseline and increasing the photometric depth, in addition to affording improved proper motion (PM) measurements, as a result of combining both the VVV and VVVX datasets.

Among the targets found as variable sources in the VVV data, some are specially important since their behaviour does not seem to fit any currently known class of stellar variability. These objects are labeled as "What Is This" (WIT) objects. Most of VVV-WIT objects found up to now are high amplitude variables, including a transient of unknown character, proposed to be a nearby supernova, a rare Galactic nova, or a stellar merger (VVV-WIT-06, Minniti et al. 2017). Here we present the case of VVV-WIT-07, an intriguing variable source and unique in its nature found in the current VVV data.

2 OBSERVATIONS AND ARCHIVE DATA

VVV data consist of two sets of casi-simultaneous ZY and $JHK_{\rm s}$ photometry, and a variability campaign in the $K_{\rm s}$ band with 50 - 200 epochs carried out over many years (2010 – 2016). The strategy of the VVVX Survey is similar to the VVV and consists of JHK_s photometry plus 3 to 10 epochs in K_s -band. In particular for the field where VVV-WIT-07 is located, and combining VVV and VVVX data, 2 sets of ZY and 4 sets of JHK_s images have been observed. In addition, 85 $K_{\rm s}$ -band epochs were taken from May 10 2010 to May 25 2018 with irregular cadence. The VVV and VVVX data presented here are based on the default "aper3" photometry provided by the Cambridge Astronomical Survey Unit (CASU) on the stacked VVV tile images (for details see Saito et al. 2012). The set of 85 K_s -band epochs from VVV and VVV-X available for VVV-WIT-07 is presented in Appendix A.



Figure 1. VVV JHK_s false-color image of VVV-WIT-007 area. The field size is $60'' \times 50''$ and oriented in equatorial coordinates. North is towards the top and East towards the left. The reticle at the centre marks VVV-WIT-007.

VVV-WIT-07 is a stellar source located in the Galactic plane at coordinates RA, DEC (J2000) = 17:26:29.387, -35:40:56.20,corresponding to l, b = -7.8580, -0.2357 deg. Figure 1 shows that the object is a relatively isolated point source (i.e. not blended), and seems to be bluer than the surrounding fainter field stars, which appear to be more affected by reddening. This object was found serendipitously in a search for large amplitude objects in the VVV data (e.g. novae and LPVs). It stood out in our search because it had a large amplitude dip in 2012. The VVV-WIT-07 K_s -band light curve presents an irregular behaviour with a main deep, narrow eclipse/dip of $\Delta K_s \sim 1.8$ mag delayed with respect to a broad and shallower dip around July 2012 (see Fig. 2). The narrow eclipse/dip lasts by ~ 11 days while the broad dip is seen with a width of ~ 48 days. The variation in magnitude from the median $\langle K_s \rangle = 14.35$ mag measured over the other epochs implies that $\sim 80\%$ of the flux in K_s is missing during the event on July 2012.

Archive search at the VVV-WIT-07 position shows several measurements in different wavelengths spanning from Gaia data in the optical (Gaia Collaboration et al. 2018) to GLIMPSE observations in the mid-IR (Spitzer Science 2009). Gaia, DECaPS (Schlafly et al. 2017) and VPHAS+ (Drew et al. 2016) observations are contemporaneous with our VVV/VVVX data, however epochs for Gaia observations are not yet publicly available¹. The multi-wavelength dataset is presented in Table 1 and a photospectrum combining all this information is shown in the top panel of Fig. 3.

Given the interesting unknown nature of this object, follow-up near-IR spectra of VVV-WIT-07 were taken with the SofI spectrograph at ESO NTT telescope on UT February 02 2016 (Grism Red - GR, J to K-band, $\lambda \sim 1.5-2.5 \ \mu m$) and with the OSIRIS spectrograph at the SOAR Telescope on UT June 18 2016 (K-band, $R \sim 1200$, $\lambda \sim 2.0-2.3 \ \mu m$).

¹ Individual epoch data for the Gaia observations will be released only with the final catalogue, as described in cosmos.esa.int/web/gaia/release



Figure 2. VVV K_s -band light curve of VVV-WIT-007. There is a total of 85 data-points covering the 2010-2018 seasons, including data from the VVVX survey. Epochs of contemporary multiwavelength observations as well as of spectroscopic observations are marked. The insert shows an expanded view around the event in July 2012.

Both data sets were data reduced using standard IRAF tasks. The resulting spectra are basically flat, with a continuum without prominent lines in emission or absorption (see Fig. 3). The only likely features seem to correspond to weak H, C and Mg absorption lines, suggesting the spectrum of a stellar source.

3 DISCUSSION

3.1 Colour data and the problem of the distance

Figure 4 shows the Y vs. (Z-Y) and the K_s vs. $(J-K_s)$ colormagnitude diagrams (CMDs) for a 10 arcmin radius region around the position of VVV-WIT-07. According to the VVV extinction maps (Gonzalez et al. 2012) this region has an extinction of $A_K = 1.85$ mag (integrated along the entire line of sight), corresponding to E(J-K) = 3.51 mag, assuming the law of Nishiyama et al. (2009). The CMDs suggest that VVV-WIT-07 is a Galactic object located in the foreground disk region. The VVV colors are roughly constant over time (see Table 1 for the observed epochs) and consistent either with a reddened MS star (spectral type G or earlier, e.g. Alonso-García et al. 2018) or a pre-MS star, but the surroundings do not show evidence of an active star formation region (see Fig. 1).

The proper motion (PM) of VVV-WIT-07 as measured by the VVV InfraRed Astrometric Catalogue (VIRAC, Smith et al. 2018) is $\mu = 2.826 \pm 0.863 \text{ masyr}^{-1}$ $(\mu_{\alpha}, \mu_{\delta}=2.469, 1.374 \text{ masyr}^{-1})$. Those values are as expected for disk field stars, that show an asymmetric drift. Even though the distance of VVV-WIT-07 is uncertain, the VIRAC PM significantly different from zero is an indication that the object is relatively nearby. While photometric data for VVV-WIT-07 are available in Gaia DR2 (source ID 5974962995291907584, Gaia Collaboration et al. 2018) no PM or parallaxes measurements are reported yet for the object in Gaia DR2. The lack of motion measurements in Gaia may suggest a minimum distance for VVV-WIT-07, for instance, in Poggio et al. (2018) Gaia data are used to map



Figure 3. Top: Photospectrum of VVV-WIT-007 including archive data from different observatories/surveys. Data covers from optical to mid-IR (see Table 1). The extinction for a 10' region around the target position is $A_K = 1.85$ mag. Bottom: near-IR spectra taken at ESO-NTT on Feb 02 2016 (*J*- to *K*-band) and at SOAR on Jun 18 2016 (*K*-band). The spectra are basically flat, showing likely weak H absorption features. Strong telluric lines dominate the SofI spectrum in the region 1.8 μ m $\lesssim \lambda \lesssim 2.0 \ \mu$ m.

the MW disk, including towards the position of VVV-WIT-07, to distances of up to r ~ 7 kpc, close to the Galactic center. On the other hand, VVV-WIT-07 (G=20.56 mag) is near the limiting magnitude of Gaia and an archive search in the region around VVV-WIT-07 shows that only a small fraction ($\leq 1/4$) of sources at similar magnitude (G > 20.5mag) present measured PMs and parallaxes in Gaia DR2.

For a foreground disk object, the total extinction as

Table 1. Archive data for VVV-WIT-07. Observations cover from optical to mid-IR. The VVV K_s epochs presented here correspond to the ones observed simultaneously with the J and H bands. Gaia, DECaPS and VPHAS+ observations are contemporaneous with the VVV/VVX data, however, epochs for Gaia observations are not yet publicly available (see Section 2).

Filter	Survey	λ_C [μ m]	Mag [mag]	Epoch [JD]
G	Gaia DR2 ¹	0.532	20.565 ± 0.016	NA
r	$DECaPS^2$	0.638	21.293 ± 0.044	2457805
BP	Gaia $IGSL^3$	0.673	17.545 ± 0.500	NA
i	VPHAS+4	0.770	20.25 ± 0.09	2456155
i	$DECaPS^2$	0.777	19.442 ± 0.018	2457805
RP	Gaia IGSL ³	0.797	17.545 ± 0.500	NA
Ζ	VVV	0.878	18.356 ± 0.040	2455766
Ζ	VVV	"	17.957 ± 0.032	2457162
z	$DECaPS^2$	0.911	18.105 ± 0.007	2457805
Y	$DECaPS^2$	0.985	17.574 ± 0.022	2457805
Y	VVV	1.021	17.125 ± 0.021	2455766
Y	VVV	"	16.814 ± 0.018	2457162
J	$2MASS^5$	1.240	15.830 ± 0.010	2451035
J	DENIS ⁶	1.221	15.666 ± 0.230	2451062
J	VVV	1.254	15.804 ± 0.061	2455326
J	VVV	"	15.709 ± 0.010	2455387
J	VVV	"	15.777 ± 0.011	2455411
J	VVVX	"	15.707 ± 0.011	2457279
H	$2MASS^5$	1.664	14.839 ± 0.094	2451035
H	VVV	1.646	14.953 ± 0.013	2455326
H	VVV	"	14.897 ± 0.014	2455387
H	VVV	"	14.961 ± 0.017	2455411
H	VVVX	"	14.912 ± 0.017	2457279
Κ	$2MASS^5$	2.164	13.702*	2451035
K_s	VVV	2.149	14.356 ± 0.022	2455326
K_s	VVV	"	14.402 ± 0.025	2455387
K_s	VVV	"	14.384 ± 0.021	2455411
K_s	VVVX	"	14.368 ± 0.024	2457279
3.6	$GLIMPSE^7$	3.545	14.338 ± 0.175	2453742
4.5	GLIMPSE ⁷	4.442	13.923 ± 0.354	2453742

¹Gaia Collaboration et al. (2018); ²Schlafly et al. (2017); ³Smart & Nicastro (2013) ⁴Drew et al. (2016); ⁵Cutri et al. (2003); ⁶DENIS Consortium (2005); ⁷Spitzer Science (2009); ^{*}upper limit.

calculated by the VVV maps is certainly overestimated. $A_{Ks} = 1.85$ mag corresponds to $A_V > 15$ mag in the optical, turning the slope of Photospectrum of VVV-WIT-07 presented in Fig. 3 to peak at $\lambda < 0.5 \ \mu m$, translating to a black-body temperature higher than T = 5400 K. 3-D extinction maps (Schultheis et al. 2014) show that the extinction increases linearly with the distance up to D < 8 kpc in the VVV-WIT-07 direction, making the interpretation of the photospectrum of VVV-WIT-07, presented in the top panel of Fig. 3 puzzling and dependent of a better distance estimation. Moreover, a photospectrum for VVV-WIT-07 using multi-epoch data taken at different epochs over almost a decade must be seen with caution since the object is clearly variable over time.

Both SofI and SOAR near-IR spectra are featureless, having no prominent lines in emission or absorption, excluding the possibility of VVV-WIT-07 as an emission line object such as a cataclysmic variable (CV) or a Nova star. The absence of $H\alpha$ data in VPHAS+ would confirm this interpretation. The shallow absorption features are interpreted as



Figure 4. *Y* vs. (Z - Y) (left) and K_s vs. $(J - K_s)$ CMDs (right) for stellar sources within 10 arcmin radii around the target position. Colors for VVV-WIT-07 from the VVV and VVVX surveys are marked as blue dots: two sets of *ZY* and four of *JHK*_s colors, taken at different epochs (see Table 1). High extinction limits the number of sources in the *Y* vs. (Z - Y) CMD. In the K_s vs. $(J-K_s)$ CMD a reddening vector corresponding to an extinction of $A_{Ks} = 1.85$ mag, assuming the Nishiyama et al. (2009) extinction law, is also shown.

H, C and Mg absorption lines, that reinforces the hypothesis of a main sequence stellar source.

We fit the photoespectrum using the Virtual Observatory SED Analyzer (VOSA, Bayo et al. 2008) with the disclaimer that the photometry was collected over nearly a decade and may be affected by the source's variability. In this analysis we masked out Gaia, 2MASS K-band and VPHAS+ data, since 2MASS K-band magnitude is at the upper limit and Gaia and VPHAS+ are close to their detection limits.

We made use of Kurucz and BT-Settl models (Castelli et al. 1997; Allard et al. 2012) with solar metallicity, T_{eff} between 3500 and 15000 K and log g between 0 and 5, and assuming A_V between 1 – 12 mag ($A_{Ks} \leq 1.4$ mag). For this exercise we obtained either $A_v = 5$ and $T_{eff} = 3,500$ K and log g = 5 which is unlikely because that would mean a nearby red dwarf (d < 300 pc for a M1 dwarf). The position on the CMDs, the spectra, the PM and lack of a parallax do not support this result. The other solution was $A_V \sim 9$ mag with a best fit in $T_{eff} \sim 10,000$ K and $\log g \sim 3$, slightly high for an A0V star. If that is the case and we assume a regular A0V star the distance will be $\gtrsim 3.5$ kpc.

Allowing for even higher extinction of $A_v = 15 \text{ mag}$ (corresponding to $A_{Ks} \sim 1.8 \text{ mag}$) leads to $A_V \sim 9 \text{ mag}$, with $T_{eff} \sim 9,000 \text{ K}$ and $\log g \sim 2.5 - 3$. This implies the presence a nearby (d $\leq 3.5 \text{ kpc}$) dust cloud with extinction, contrary to the 3-D extinction maps that show a smooth, linear increment of A_{Ks} with the distance in this line of sight (e.g. Schultheis et al. 2014).

3.2 To be or not to be periodic?

The light curve of VVV-WIT-07 presented in Fig. 2 shows a sequence of dips, with a likely deep eclipse in July 2012. While these are certainly recurrent, the presence of a regular periodicity is not obvious. A search for periodicity using a fast Lomb-Scargle algorithm (VanderPlas & Ivezić 2015) results in two tentative periods at $P \sim 322$ days (score 0.462)



Figure 5. Periodogram (top panel) and phase-folded light curve for the tentative periods of $P \sim 322$ days (middle panel, score 0.462 in the periodogram) and $P \sim 170$ days (bottom panel, score 0.400).

and $P \sim 170$ days (score 0.400). Figure 5 shows the periodogram and the phase-folded light curves for both periods. Despite its higher significance, a period of $P \sim 322$ days breaks the shape of the main eclipse/dip of July 2012 by including a data point at $K_{\rm s} \sim 14.7$ mag at the ingress of the event ($\phi \sim 0.48$), moreover data points seen to spread out near phase $\phi \sim 0.65 - 0.70$. On the other hand, for the period of $P \sim 170$ days a couple of outlier data points are seen prior $(\phi = 0.3)$ and after $(\phi \sim 0.75 \text{ and } 0.75)$ the main eclipse/dip. Thus, we are not able to conclusively establish a period for VVV-WIT-07. If the $P \sim 170$ days is correct, an ephemeris for the object can be calculated to predict that VVV-WIT-07 should fall down to $K_{\rm s} \gtrsim 14.7$ mag and possibly become fainter than 16 mag in K_s -band, three times in the next year, at around January 21, July 10, and December 27, 2019. In the case of $P \sim 322$ days another eclipse/dip should occur around August 7, 2019.

4 POSSIBLE INTERPRETATIONS

The features found in the light curve of VVV-WIT-07 are similar to those seen in J1407 (= V1400 Cen, Mamajek et al. 2012). J1407 is consistent with a pre-MS K5 dwarf with a ring system eclipsing the star. Its light curve has a main eclipse of > 3.3 mag and multiple dimming events of > 0.5mag. During the main eclipse the object fades from $V \sim 12.4$ to $V \sim 15.8$, or a decrease of $\sim 95\%$ in the flux, compared with $\sim 80\%$ of VVV-WIT-07 in the near-IR. The main eclipses are similar in shape, with a smooth ingress and a shoulder in the egress, typical for the eclipse of an extended object such as a disk or ring, which is the preferred explanation in the case of J1407. If VVV-WIT-07 has the same nature of the Mamajek object, which has a lower limit on the period of 850 days, the absence of a firm period determination of VVV-WIT-07 can be explained by the irregular cadence of our light curve, which presents large windows of no coverage, especially in the last 2 years.

Another object that is possibly similar to VVV-WIT-07 is KIC 8462852 (Boyajian's star, Boyajian et al. 2016). The object is a F3 IV/V star showing irregular and aperiodic dips, however the dips are shallow at 20% of the normalized flux, compared with ~ 80% of VVV-WIT-07. Boyajian's star has been followed up since its discovery and the most accepted hypothesis for its dips is the occultation by orbiting material (e.g. uneven rings of dust, dusty planetesimals or even a swarm of comet-like bodies Boyajian et al. 2016; Neslušan & Budaj 2017). A possible period for Boyajian's star is still unknown, with some recent works suggesting the presence of a likely recurrence ranging from $P \sim 1600$ days up to $P \sim 12$ years (Bourne & Gary 2017; Sacco et al. 2017; Ballesteros et al. 2018).

Alternative scenarios for VVV-WIT-07 include a "dipper" T Tauri star with clumpy dust structures orbiting in the inner disk that transit our line of sight (e.g. Rodriguez et al. 2017), or even a long period, high-inclination X-ray binary. The deep, narrow eclipse delayed with respect to a broad and shallower dip is reminiscent of the morphology seen in high-inclination low-mass X-ray binaries (LMXB, e.g. Parmar et al. 1986; Baptista et al. 2002). However, LMXBs are restricted to orbital periods of less than a few days while high-mass x-ray binaries (HMXB) can be found at P_{orb} up to hundreds of days (e.g. X1145-619 has $P_{orb} = 187.5 d$, Watson et al. 1981). Moreover, in this scenario optical and IR spectra would be dominated by the mass-donor companion star, and should show rotationally-broadened hydrogen absorption lines at epochs of no mass ejection episodes, which is not the seen in the spectra of VVV-WIT-07.

An R Coronae Borealis (R CrB) classification could be also suggested, but the light curve of VVV-WIT-07 does not resemble what is typically observed in other R CrB systems in the near-IR, specially because of the fast dimming episode in July 2012. Moreover, the position in the CMD is unlikely for an R CrB. In particular, if this were a high-luminosity R CrB star undergoing unusually fast dimming episodes, VVV-WIT-07 would be located well beyond the Milky Way disk, which is inconsistent with the measured PM and amount of foreground reddening. For instance, if VVV-WIT-07 has the same absolute magnitude of the R CrB class prototype $(M_K \simeq -6 \text{ mag})^2$ that would translate to a distance to VVV-WIT-07 of $d \gtrsim 50 \text{ kpc}$ (using $m_{K_s} = 14.35 \text{ mag}$ and $A_K = 1.85 \text{ mag}$, see Sections 2 and 3).

5 CONCLUSIONS

We have presented the discovery of VVV-WIT-07, a unique variable source located in the Galactic disk, identified in the VVV Survey. VVV-WIT-07 is a Galactic object located in the foreground disk. Its light-curve shows dimming episodes, resembling the features seen in Boyajian's star and in Mamajek's object. Other possibilities also relate to the young stellar zoo or the eclipse of extended bodies in a MS star. At present, with the information at hand, none of the proposed scenarios can be conclusively established. In any case, all of these possibilities are interesting in their own right.

If this is another Mamajek object, it means that these objects are likely more common than previously realized, as is shown by the example of the discovered of OGLE LMC-ECL-11893 (Scott et al. 2014), an eclipsing B9III star $(P_{orb}=468 \text{ days})$ consistent with a dense circumstellar dust disk structure; and PDS 110, an eclipsing system with likely transits by a companion with a circumsecondary disc (Osborn et al. 2017). Indeed, near-IR surveys like VVV and UKIDSS-GPS (Lucas et al. 2008) have only recently, after a deliberate search, been found to contain a number of intriguing large-amplitude YSOs (Contreras Peña et al. 2017; Lucas et al. 2017). Thus, surveys like ours, apart of course from its irregular cadence, may perhaps not have found objects like WIT-VVV-07 more often primarily because they were not looking specifically for this kind of variability. The next generation of synoptic surveys such as LSST, WFIRST and PLATO will certainly be major contributors to this field, yielding many other interesting discoveries.

ACKNOWLEDGEMENTS

We gratefully acknowledge the use of data from the ESO Public Survey program IDs 179.B-2002 and 198.B-2004 taken with the VISTA telescope, and data products from the Cambridge Astronomical Survey Unit (CASU). This publication makes use of VOSA, developed under the Spanish Virtual Observatory project supported from the Spanish MINECO through grant AyA2017-84089. R.K.S. acknowledges support from CNPq/Brazil through projects 308968/2016-6 and 421687/2016-9. Support for the authors is provided by the BASAL CONICYT Center for Astrophysics and Associated Technologies (CATA) through grant AFB-170002, and the Ministry for the Economy, Development, and Tourism, Programa Iniciativa Científica Milenio through grant IC120009, awarded to the Millennium Institute of Astrophysics (MAS). D.M. acknowledges support from FONDECYT through project Regular #1170121. F.G. acknowledges support from CONICYT-PCHA Doctorado Nacional 2017-21171485 and from Proyecto FONDE-CYT REGULAR 1150345. C.C. acknowledges support from from ICM Núcleo Milenio de Formación Planetaria, NPF

and from project CONICYT PAI/Concurso Nacional Insercion en la Academia, convocatoria 2015, folio 79150049. M.C. gratefully acknowledges additional support by Germany's DAAD and DFG agencies, in addition to FONDE-CYT grant #1171273 and CONICYT/RCUK's PCI grant DPI20140066. R.A. acknowledges financial support from the DIDULS Regular PR17142 by Universidad de La Serena. The authors would like to thank Eric Mamajek for the helpful suggestions about the interpretation of VVV-WIT-07 data.

REFERENCES

- Allard, F., Homeier, D., & Freytag, B. 2012, Philosophical Transactions of the Royal Society of London Series A, 370, 2765
- Alonso-García, J., Saito, R. K., Hempel, M., et al. 2018, arXiv:1808.06139
- Ballesteros, F. J., Arnalte-Mur, P., Fernandez-Soto, A., & Martínez, V. J. 2018, MNRAS, 473, L21
- Baptista, R., Bortoletto, A., & Harlaftis, E. T. 2002, MNRAS, 335, 665
- Bayo, A., Rodrigo, C., Barrado Y Navascués, D., et al. 2008, A&A, 492, 277
- Bourne, R., & Gary, B. 2017, Research Notes of the American Astronomical Society, 1, 33
- Boyajian, T. S., LaCourse, D. M., Rappaport, S. A., et al. 2016, MNRAS, 457, 3988
- Castelli, F., Gratton, R. G., & Kurucz, R. L. 1997, A&A, 318, 841
- Contreras Peña, C., Lucas, P. W., Minniti, D., et al. 2017, MN-RAS, 465, 3011
- Contreras Peña, C., Lucas, P. W., Kurtev, R., et al. 2017, MN-RAS, 465, 3039
- Cutri, R. M., Skrutskie, M. F., van Dyk, S., et al. 2003, "The IRSA 2MASS All-Sky Point Source Catalog, NASA/IPAC Infrared Science Archive. <A
- DENIS Consortium 2005, VizieR Online Data Catalog, 2263,
- Drew, J. E., Gonzalez-Solares, E., Greimel, R., et al. 2016, VizieR Online Data Catalog, 2341
- Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, A&A, 616, A1
- Gonzalez, O. A., Rejkuba, M., Zoccali, M., et al. 2012, A&A, 543, A13
- Ivezic, Z., Tyson, J. A., Abel, B., et al. 2008, arXiv:0805.2366
- Lucas, P. W., Hoare, M. G., Longmore, A., et al. 2008, MNRAS, 391–136
- Lucas, P. W., Smith, L. C., Contreras Peña, C., et al. 2017, MN-RAS, 472, 2990
- Mamajek, E. E., Quillen, A. C., Pecaut, M. J., et al. 2012, AJ, 143, 72
- Mowlavi, N., Barblan, F., Saesen, S., & Eyer, L. 2013, A&A, 554, A108
- Minniti, D., Lucas, P. W., Emerson, J. P., et al. 2010, New Astron., 15, 433
- Minniti, D., Saito, R. K., Forster, F., et al. 2017, ApJ, 849, L23
- Minniti, D. 2018, in The Vatican Observatory, Castel Gandolfo: 80th Anniversary Celebration (ed. G. Gionti, S.J., & J.-B. Kikwaya Eluo, S.J). Astrophysics and Space Science Proceedings, 51, 63
- Neslušan, L., & Budaj, J. 2017, A&A, 600, A86
- Nishiyama, S., Tamura, M., Hatano, H., et al. 2009, ApJ, 696, 1407
- Osborn, H. P., Rodriguez, J. E., Kenworthy, M. A., et al. 2017, MNRAS, 471, 740
- Parmar, A. N., White, N. E., Giommi, P., & Gottwald, M. 1986, ApJ, 308, 199

 $^{^2\} simbad.u-strasbg.fr/simbad/sim-id?Ident=R+Coronae+Borealis$

VVV-WIT-07 7

- Pietrukowicz, P., Dziembowski, W. A., Latour, M., et al. 2017, Nature Astronomy, 1, 0166
- Poggio, E., Drimmel, R., Lattanzi, M. G., et al. 2018, arXiv:1805.03171
- Rauer, H., Catala, C., Aerts, C., et al. 2014, Experimental Astronomy, 38, 249
- Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2015, Journal of Astronomical Telescopes, Instruments, and Systems, 1, 014003
- Rodriguez, J. E., Ansdell, M., Oelkers, R. J., et al. 2017, ApJ, 848, 97
- Sacco, G., Ngo, L., & Modolo, J. 2017, arXiv:1710.01081
- Schlafly, E. F., Green, G. M., Lang, D., et al. 2017, arXiv:1710.01309 $\,$
- Saito, R. K., Hempel, M., Minniti, D., et al. 2012, A&A, 537, A107
- Schultheis, M., Chen, B. Q., Jiang, B. W., et al. 2014, A&A, 566, A120
- Scott, E. L., Mamajek, E. E., Pecaut, M. J., et al. 2014, ApJ, 797, 6
- Smart, R. L., & Nicastro, L. 2013, VizieR Online Data Catalog, 1324,
- Smith, L. C., Lucas, P. W., Kurtev, R., et al. 2018, MNRAS, 474, 1826
- Spitzer Science, C. 2009, VizieR Online Data Catalog, 2293,
- VanderPlas, J. T., & Ivezić, Ž. 2015, ApJ, 812, 18
- Watson, M. G., Warwick, R. S., & Ricketts, M. J. 1981, MNRAS, 195, 197

APPENDIX A: VVV-WIT-07 LIGHT CURVE

Here we present the 85 $K_{\rm s}$ -band data-points of VVV-WIT-07 available from VVV/VVV-X and used to build the light curve presented in Fig. 2. The photometric flag in all measurements is -1, corresponding to a stellar source as described in Saito et al. (2012).

This paper has been typeset from a $\mathrm{T}_{\mathrm{E}}\mathrm{X}/\mathrm{I}\!\!^{\mathrm{A}}\mathrm{T}_{\mathrm{E}}\mathrm{X}$ file prepared by the author.

MJD	$K_{\rm s}$ -band
(days)	(mag)
55326.3237	14.356 ± 0.022
55387.2660	14.402 ± 0.025
55411.1085	14.384 ± 0.021
55484.0358	14.446 ± 0.026
55690.3995	14.377 ± 0.025
55696.3680	14.381 ± 0.024
55697.3311	14.336 ± 0.022
55795.0961	14.700 ± 0.034
55807.0662	14.923 ± 0.041
55825.1012	14.974 ± 0.041
56084.1562	14.630 ± 0.027
56089.2537	14.716 ± 0.028
56094.2113	14.760 ± 0.030
56096.0677	14.781 ± 0.037
56099.1924	14.884 ± 0.054
56112.2212	14.917 ± 0.036
56114.1422	14.898 ± 0.035
56122.1067	15.171 ± 0.048
56123.0269	15.235 ± 0.060
56124.0031	16.164 ± 0.132
56124.9651	$\texttt{15.690} \pm \texttt{0.087}$

MJD	Khand
(do-ra)	(mcm)
(days)	(mag)
56106 1100	14 704 0 022
50120.1122	14.194±0.033
56126.1728	14.772 ± 0.033
56128.2039	14.650 ± 0.036
56130.1034	14.593 ± 0.030
E6120 01E0	14 594 1 0 000
50150.2159	14.564 ± 0.029
56132.9995	14.558 ± 0.027
56133.0766	14.550 ± 0.026
56134.0311	14.612 ± 0.031
56135 1495	14596 ± 0.050
50100.1400	14.000 ± 0.000
56141.1675	14.540 ± 0.026
56144.0130	14.559 ± 0.030
56151.0198	14.510 ± 0.028
56156.0239	14.537 ± 0.032
56162 1016	$14 = 502 \pm 0.026$
50102.1010	14.502 ± 0.020
56163.0295	14.504 ± 0.024
56175.9971	14.516 ± 0.034
56176.0734	14.498 ± 0.037
56188 0512	14 498 + 0 027
56000 0274	14 456 + 0.021
56202.0374	14.450 ± 0.024
56213.9876	14.532 ± 0.033
56478.9848	14.491 ± 0.031
56488.9741	14.439 ± 0.025
56490 2115	$14 \ 436 \pm 0 \ 025$
56501 0000	14.405 + 0.020
56501.0208	14.435 ± 0.027
56502.0810	14.445 ± 0.024
56503.1196	14.410 ± 0.023
56505.0062	14.319 ± 0.044
56506 0725	11.010 ± 0.011 14.432 ± 0.025
50500.0725	14.432 ± 0.025
56513.9928	14.447 ± 0.031
56514.0887	14.487 ± 0.032
56515.0051	14.443 ± 0.029
56515 1139	14 411 + 0 024
56507 0010	14, 200 + 0, 000
56527.0019	14.382 ± 0.022
56531.1395	14.475 ± 0.028
56553.0009	14.405 ± 0.022
56566.0279	14.393 ± 0.023
56578 0104	$14 \ 412 \pm 0 \ 025$
56006 0060	14 596 + 0 046
56806.2868	14.586 ± 0.046
56810.2445	14.542 ± 0.027
56814.1102	14.614 ± 0.029
56817.0782	14.707 ± 0.037
56827 1137	$1/1533 \pm 0.03/$
50027.1157	14.505 ± 0.004
56827.2208	14.537 ± 0.037
56830.0180	14.480 ± 0.025
56831.1165	14.509 ± 0.030
56836.2591	14.496 ± 0.035
56837 2257	$14 490 \pm 0.026$
50001.2201	14.447 0.020
56838.0742	14.447 ± 0.025
56838.1785	14.468 ± 0.025
56841.1300	14.457 ± 0.025
56851.1179	14.422 ± 0.023
56993 1995	1/1 $1/2 + 0.020$
50005.1025	14.422 ± 0.029
56886.1011	14.390 ± 0.026
56910.0692	14.398 ± 0.026
56919.1077	14.388 ± 0.026
57279.0012	14.368 ± 0.024
5758/ 106/	$1/1 3/6 \pm 0.020$
57504.1204	14.040 ± 0.020
51926.3172	14.307 ± 0.042
57933.3156	14.349 ± 0.033
58210.3311	14.379 ± 0.033
58263.2300	14.301 ± 0.025
59010 2011	
50210.3311	14.319±0.033
58263.2300	14.301 ± 0.025
58264.1774	14.350 ± 0.029